Decision-making on local flood risk measures in area development in unembanked areas

Master Thesis

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Gemeente Rotterdam

Colophon

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Gemeente Rotterdam

‘A society grows great when old men plant trees in whose shade they know they shall never sit.’

- Greek proverb

Preface

While working on my master's thesis, the proverb on the previous page has continually lingered in my mind for several reasons. Firstly, because I simply think it is a lovely proverb. But more importantly, given the parallels it shares with the theme of this research: the adoption of climate-adaptive measures. While the saying may not directly relate to reducing flood risks, planting trees for shade contributions to alleviating heat stress; another growing concern due to climate change. Moreover, it pertains to the dimension of time, highlighting that what we build and create now has an impact on future generations. Additionally, this sentence is used in Ricky Gervais' comedy series *'After Life'* and, frankly, I could use some distraction during the more stressful periods of my thesis research. Lastly, it reminds me of the transience of life; I like to reflect on the passing of my dear grandmother during the course of this research and would like to dedicate this work to her. All in all, I hope the results of my research stay with you and stick in your mind, just like this quote did with me for the last months.

First and foremost, I would like to express my heartfelt gratitude to the members of my graduation committee, Ellen van Bueren, Audrey Esteban and Matthijs Kok. Regardless of whether you were working on the other side of the world, on vacation, or busy with various other commitments, you always managed to carve out time in your busy schedules to assist me. I am incredibly thankful for that. I have gained a wealth of knowledge and insights from your extensive expertise and years of experience in the fields of water management and the built environment. The engaging discussions during our meetings have provided me with fresh perspectives and fuelled my enthusiasm to delve deeper into the subject matter.

Secondly, I would like to extend my appreciation to Vera Konings for providing me with the opportunity to conduct my research at the municipality of Rotterdam. I want to express my gratitude for the support and trust you have shown throughout my graduation journey. Additionally, you opened many doors for me through the municipality's network, and I appreciate your continuous invitations and encouragement to participate in numerous meetings and events. This has been very educational. I would also like to thank the other colleagues at Rotterdam, especially Dook Ligthart, Liselotte Mesu, and Corjan Gebraad, for your assistance and the enjoyable time at the municipality.

Third, I would like to thank everyone else who has contributed to this research. Thank you for the time and effort you have taken to speak with me, and thank you for the engaging conversations about my graduation topic.

Finally, I would like to thank my friends and family for all their support throughout the past months. Thank you for all your advice and motivation. And thank you for listening to all my doubts and grumbling; at least it contributed a little to the awareness of unembanked areas.

Enjoy reading this report!

Louis Nelen
Rotterdam, December 2023

Summary

Cities worldwide are already impacted by climate hazards like heavy precipitation, heat stress, flooding, drought, which are projected to worsen due to climate change. Unless measures are taken, the probability of flooding will increase due to sea-level rise, higher river peak discharges, and land subsidence. Areas not protected by dikes, known as unembanked areas (*NL: buitendijkse gebieden*) are particularly vulnerable due to their direct location to the sea or river. However, pushed by urbanization and the housing crisis, and the perceived attractiveness of the higher elevated locations on the waterfront; there are many plans for area (re)developments in unembanked areas in the Netherlands. To effectively address the impacts of climate change and avoid passing on the consequences to future generations, the implementation of adaptation measures is essential for developments in unembanked areas.

These measures can be taken at different levels (e.g., regional, local or building), and the location characteristics call for a tailor-made approach. The fact that many parties are involved or affected in flood risk management and spatial planning, the dependency on decisions taken at different (governmental) levels, and uncertainties in the rate and magnitude of climate change complicates the question on how to deal with flood risks on a local level in unembanked area development. Adding to this complexity, unembanked areas have no standard safety levels as they are excluded from the Dutch Water Act and responsibilities and duties differ from the embanked areas. This is compounded by the fact that many stakeholders have a false, low or non-existing safety perception or risk awareness in unembanked areas, if they are even at all aware of what unembanked areas are.

In the light of all these elements, selecting a suitable set of flood risk measures is a complex and multifaceted task. Therefore, the aim of this research is to gain a better understanding of the decision-making process for local flood risk measures in area development in unembanked areas. For this, the main research questions is as follows:

What evaluation methods are appropriate to use in the decision-making process for local flood risk measures in area development in unembanked areas, and what are the needs of stakeholders regarding the decision-making process?

For this research, various qualitative research methods have been employed to address the main question. To start with, expert interactions such as informal bilateral meetings, gatherings, field visits, conferences, were used throughout the research period to gather information and enhance understanding of issues related to implementing climate adaptation measures in unembanked areas.

Furthermore, a literature review was conducted to examine relevant approaches and evaluation methods used in flood risk management for unembanked areas. Subsequently, several case studies were employed to investigate real-world practices of decision-making processes for adaptation measures, encompassing both completed and ongoing projects. The cities of Rotterdam, Zwolle, Vlaardingen, Hamburg, and Copenhagen were analysed for this purpose. This analysis was supported by semi-structured interviews.

Additionally, semi-structured interviews were as well used to explore the involvement of stakeholders and their impact on the implementation of flood risk measures in unembanked areas. This made it possible to identify the needs and challenges of stakeholders in implementing climate adaptation measures. Interviews were conducted with people with different roles, ranging from both private and public institutions.

However originally designed for the embanked areas, the Dutch multi-level safety (MLS) approach consisting of layers (1) prevention (2) spatial interventions (3) crisis management, is well applicable for the unembanked areas too. Although the MLS-approach is not an assessment method, it is important to note that it is a suitable method for structuring potential measures and thus can contribute to the decision-making process. The proposal to expand the MLS-approach with additional layers for (4) recovery and (5) water awareness aligns with the challenges faced in unembanked area development.

Moreover, methods such as adaptive pathways (AP), adaptive tipping points (ATP), and adaptive delta management (ADM) have been used for adaptation strategies in unembanked areas. These resilience-based planning methods offer valuable guidance in the decision-making process and serve as an effective means to facilitate ongoing decision processes by assisting decision-makers in choosing future adaptation options that align with changing environmental and societal conditions. For unembanked areas, these approaches were found to be effective methods to evaluate and select appropriate urban flood adaptation strategies. Instruments like (social) cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), or multi-criteria analysis (MCA), when applied thoughtfully within the framework of adaptive pathways, can contribute to risk-informed decision-making and the development of flexible strategies.

Now, on evaluation methods, social cost-benefit analysis is a widely used tool in flood risk management and spatial planning. This tool serves as an objective means to evaluate policy alternatives or measures, quantifying their effects, uncertainties, costs, and benefits in monetary terms for as much as possible. Different types of CBA exist, such as a complete CBA (incorporating all social costs and benefits and monetizing them as much as possible) and lighter versions like key figure or quick-scan CBAs. Other evaluation methods, including cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), and impact assessment (IA), are also commonly used in flood risk management.

Throughout the study, it has become evident that unembanked areas require a tailor-made approach to develop a suitable set of measures. In this context, social values and intangible criteria such as spatial quality, nature, cultural heritage, stress from floods, flexibility, and feasibility are crucial to include for robust decision-making on local flood risk measures. Yet, there is a lack in key figures and adequately valuation methods for these social values. So, although CBA is a widely used tool in flood risk management, to support decision-making for local flood risk measures in unembanked areas, it runs into its limitations. As well as according to the general guidance for CBA by Romijn and Renes (2013b) '*the usefulness of CBA for the decision-making process has its limits. If most important effects cannot be adequately measures or monetised, a CBA can only provide sketchy information of limited reliability and relevance.'*

For these reasons, MCA appears to be an appropriate tool to support decision-making on local flood risk measures in unembanked area development, as it is possible to include all relevant effects without having to measure or monetize them. Moreover, MCA can be combined with CEA or a form of CBA to quantify the effects that are measurable or monetizable. However, when combining with CBA, it should be clearly phrased what type of CBA is used, e.g., a 'partial' CBA (i.e., a CBA that solely focuses on (one) direct effect(s) that is/are monetizable, for example the reduction of flood risk).

Thus, to support decision-making on local flood risk measures in unembanked area development, the combination of MCA with CEA or some type of CBA is well suited. This is confirmed by literature and from real-world examples. This approach enables the balanced consideration of both essential quantitative and qualitative criteria. Moreover, using MCA facilitates the integration of diverse stakeholder perspectives, promoting a more inclusive decision-making process, which ultimately ensures broad consensus on the decisions made.

The research on risk governance in unembanked areas has clearly revealed the extensive involvement and impact of various stakeholders in the implementation of flood risk measures in unembanked areas. These stakeholders encompass a wide range, including public entities such as municipalities, provinces, water boards, and Rijkswaterstaat, as well as private entities like real estate developers, housing corporations, banks, insurers, and citizens. The primary barriers identified by stakeholders are currently associated with legal aspects, risk awareness and communication, and risk assessment of areas/properties.

There is a significant demand for well-defined guidelines, frameworks, and legal regulations governing climate-adaptive construction. Stakeholders emphasize the need for these requirements to be legally established, as stipulating and enforcing the criteria for climate-adaptive construction would create an equal playing field for all. The government is seen to play a leading role in this, both at the national level, where safety standards can be set for unembanked areas and laws can be introduced for climate-adaptive construction. At municipal level, however it is proven to be challenging, it possible to put some sort of safety levels (e.g., issue level policy in Rotterdam) in zoning plans. Moreover, interviews underscore the government's crucial role in communicating climate risks as well. Stakeholders stress the importance of specifying how risks should be assessed, ensuring a consistent risk indication for each area and its asset. Introducing a uniform approach makes it also more appealing for financial institutions, as they are more interested in the risk profile of assets rather than whether they are officially labelled as 'embanked' or 'unembanked'. Furthermore, there is an increasing demand for collaboration between private and public entities facilitate effective knowledge sharing on unembanked areas and climate-adaptive construction.

There remains a demand for a more detailed and transparent evaluation method to support decision-making for local flood risk measures in unembanked area development. There are ongoing discussions on where and how to build, and stakeholders are figuring out how to navigate this. The main recommendation is to begin by establishing principles crucial for unembanked area development and then translate them into criteria for a MCA. Part of the MCA should include the (cost-)effectiveness of various measures and should take into account both social values and local characteristics of an area. It is crucial to keep the role of evaluation methods in mind, as the ultimate decision on flood risk measures lies with the decision-maker. Further research should also look into how to legally assure climate-adaptive construction in unembanked areas, how to create more awareness on both flood risk and the unembanked areas themselves, on flood risk assessment methods and communication and how to strengthen collaboration between private and public stakeholders working in flood risk management and spatial planning.

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INTRODUCTION

1.1. Reason for research

More than half of the world's population lives in urban areas, particularly in vulnerable coastal cities (Aerts et al., 2012). The combined effect of rapid urbanization and rising flood risk poses significant threats to the sustainability and resilience of our deltas, regions, and communities (Nillesen et al., 2016). Cities around the world are already impacted by climate hazards like heavy precipitation, heat stress, flooding, drought, which are projected to worsen due to climate change (CDP Worldwide, 2022). The municipality of Rotterdam, located of in the Rhine-Meuse delta in the Netherlands, is no exception to this all and will increasingly have to deal with the effects of sea level rise and increased peak river discharge (Rotterdams WeerWoord, 2021a). Of all the natural disasters that can affect the Netherlands, flooding is the risk with potentially the highest damage costs (Regelink et al., 2017). Figure 1 shows the potential maximum damage and fatalities in Rotterdam that could occur in case of a flood and if the flood defences breach on site.

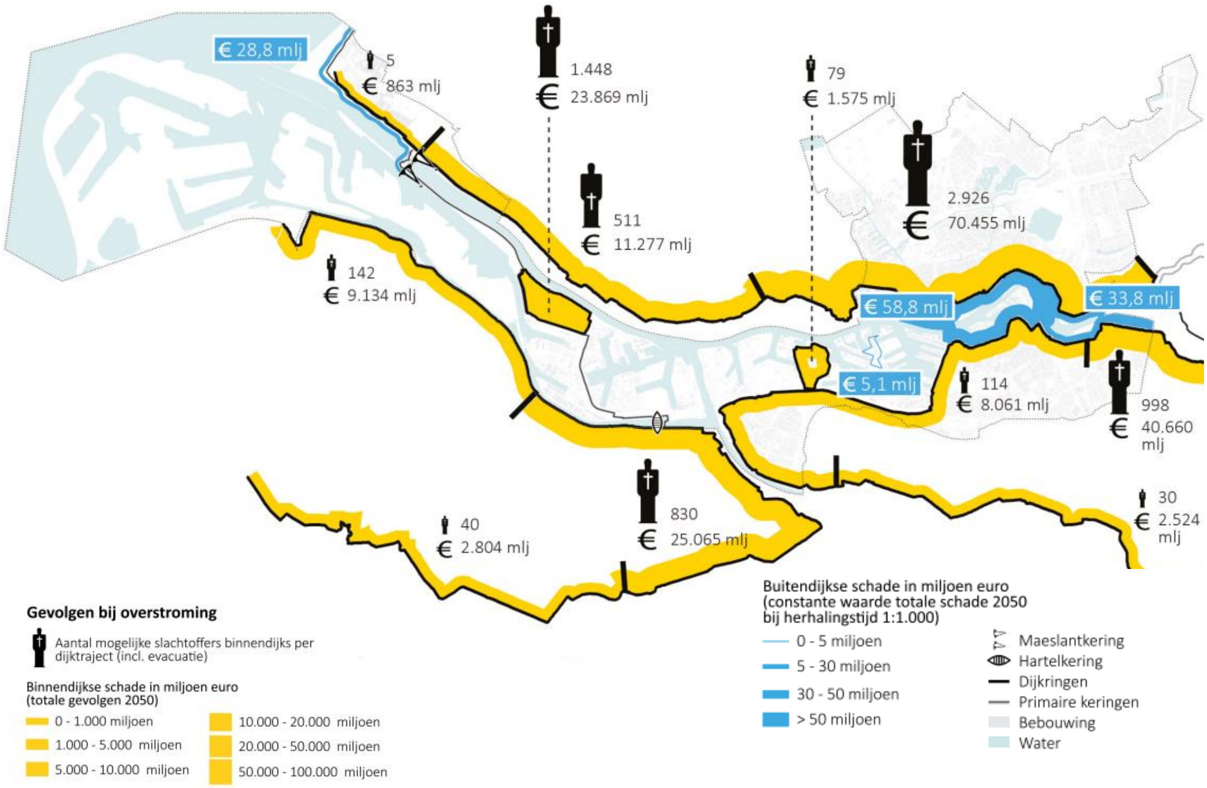

Figure 1: Possible consequences of flood in damages and fatalities in Rotterdam (Image: Defacto Stedenbouw; Source Data: DPV 2.2 31-03-2014 and RHDHV 2018, in Rotterdams WeerWoord, 2021b)

Next to climate change, the Netherlands is facing an enormous housing shortage. The city of Rotterdam is forecast to grow and in the coming twenty years Rotterdam needs to build at least 50,000 houses to meet the growing demand (Gemeente Rotterdam, 2019). This means that the inner city will densify, but also a substantial share of the urban area (re)developments will take place in areas not protected by dikes, so called unembanked areas. The municipality of Rotterdam has plans to build more than 17,500 houses in unembanked areas until 2040 (Rotterdams WeerWoord, 2022). With flood risks defined as the probability of a flood multiplied by its consequences, climate change and the plans for area development in unembanked areas thus leads to an increased flood risk. Figures 2 and 3 show housing developments and maximum flood depth in unembanked areas in Rotterdam.

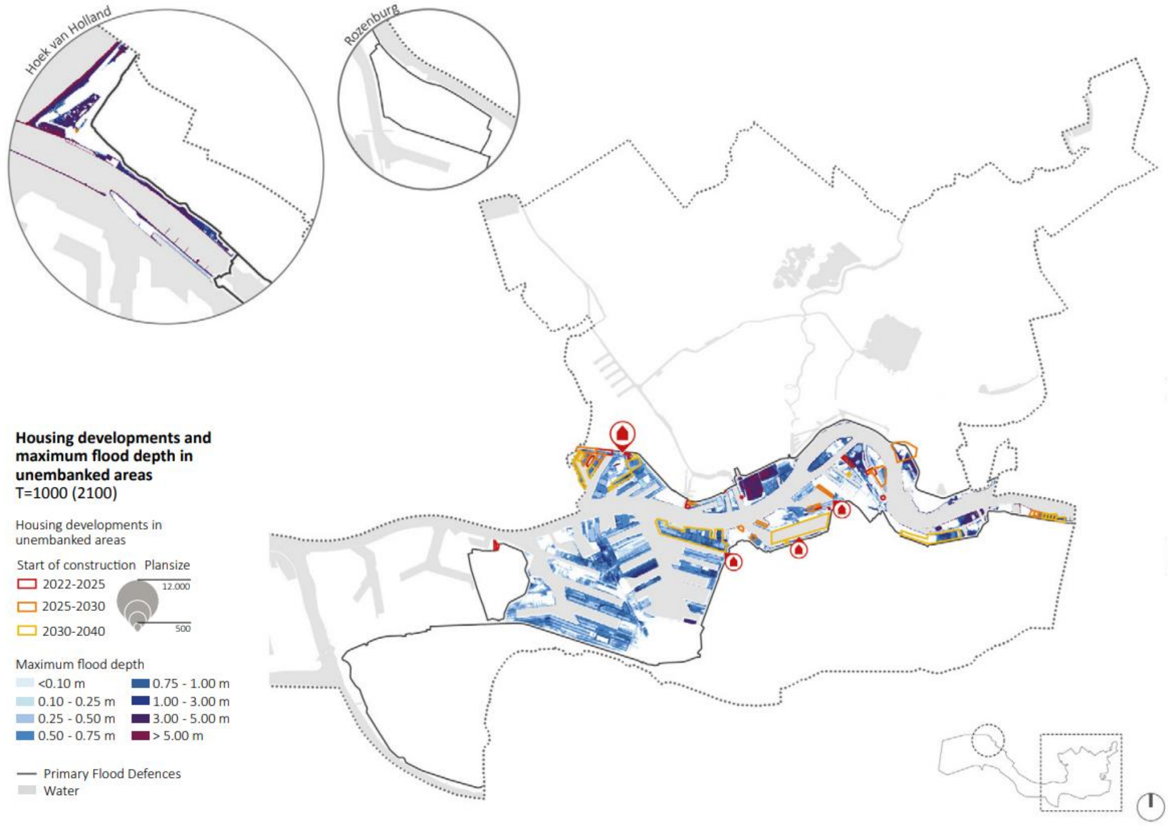

Figure 2: Flood depths in the unembanked area of Rotterdam in 2100 at T=1000, based on elevation, including the extent and period development plans (Image: Defacto Stedenbouw, Source Data: RHDHV and City of Rotterdam, in Rotterdams WeerWoord, 2023)

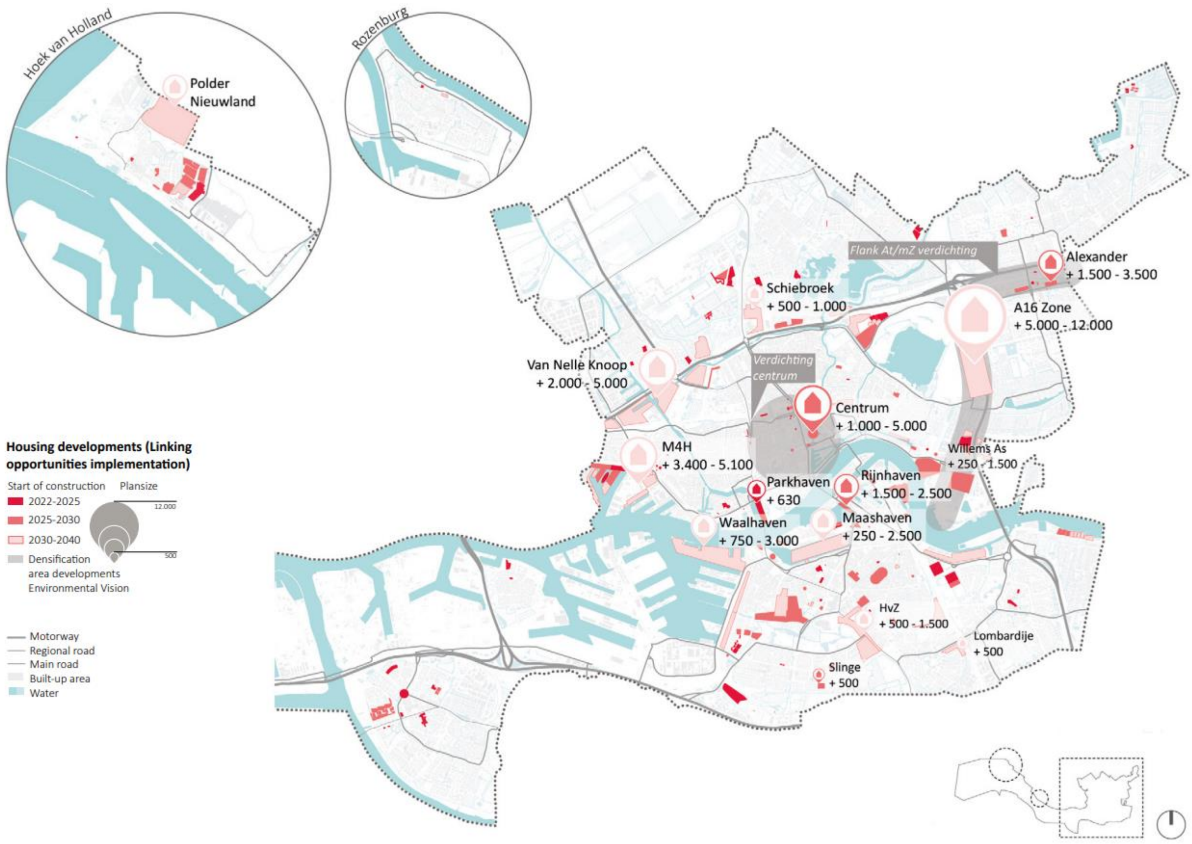

Figure 3: Implementation of opportunity map for new property in Rotterdam (Source: Plan of housing stock to 2030 and Environmental Vision - The Change City, in Rotterdams WeerWoord, 2023)

The unembanked areas face a higher probability of flooding in contrast to the embanked areas, but generally have lowers flood levels due to their often elevated or relatively high grounds. In the case of urban unembanked areas, this is mainly as they are former harbour sites that have traditionally been elevated, either naturally or artificially, to protect them from flooding. Their elevated position, centrally located in relation to the city, along with an appealing waterfront location and often featuring numerous cultural-historical characteristics, make urban unembanked areas highly attractive for area (re)development with mixed-use purposes. This is evident not only in Rotterdam but also in other parts of the Netherlands. Moreover, floods in unembanked areas can be generally well predicted (i.e. enough time to prepare in case of expected high water) and water can immediately flow back into river or sea after flooding (i.e. recovery goes quickly while in case of a flooding within the dike-ring area it would take months to pump water out). The unembanked areas are therefore attractive and suitable locations for area development, provided that the area and its buildings are safely designed from a flood risk perspective.

Unlike the embanked area where the Dutch government is legally obliged by the Water Act to provide protection against high water, in unembanked areas, residents and users themselves are responsible for preventive measures and bear their own risk for damage caused by water. The unembanked areas have no standard safety levels and there are different legal responsibilities and duties; something stakeholders say they struggle with is evident from preliminary interviews. This is compounded by the fact that many stakeholders have a false, limited or non-existing flood risk awareness in unembanked areas, if they are even at all aware of what unembanked areas entail.

Not all climate-related damage is insured and damage costs due to flooding primarily fall on the government, households, businesses and other organisations (Regelink et al., 2017). Apart from a few exceptions for companies, damage caused by water coming from the sea, a river or an inland waterway due to a primary flood defence has overflowed or failed is not insurable in the Netherlands and all houses in unembanked areas are excluded from insurance anyways (Van Hamel & Dekker, 2021; Verbond van Verzekeraars, 2023). There have been several attempts from the insurance industry in recent decades to insure flood risk on a large scale and with a mandatory character, instead of arranging compensation through a public safety net. However, this has proved recalcitrant for the time being, although there seems to be continued interest in the industry to develop new products (Regelink et al., 2017). Moreover, research shows that the costs that have to be incurred for recurrent damage repairs are many times higher than the investments to make cities climate-proof and at the same time more attractive (Nationaal Deltaprogramma Rijnmond-Drechtsteden, 2022). Thus the solution lies in reducing flood risks by either reducing the probability of an area flooding or by reducing the impact of a flooding in the area; something that all parties need to do together (Rotterdams WeerWoord, 2021a).

Urban development can serve as a window of opportunity for flood risk management (Van Herk et al., 2011). As buildings being built now have an expected lifespan of 50-100+ years, it is inevitable to consider the effects of climate change. Adaptation cannot stop sea level rise, but it can prepare for the adverse consequences; disruption, (large) financial losses and personal suffering (Rotterdams WeerWoord, 2021b). The former Delta Programme Commissioner has urged relevant ministries to take the future climate into account when building houses, with the aim of averting potential issues and damages stemming from climate change for future generations (Glas, 2021). Moreover, a parliamentary letter *(NL: Kamerbrief Water en bodem sturend)* was sent to the Dutch House of Representatives informing that water and soil should be guiding principles in future spatial planning and decision-making (Harbers & Van Heijnen, 2022).

Many parties, both public and private, are involved in flood risk management and on different system levels there are ongoing discussions and developments in the field of spatial planning and water management on where and how to build. The implementation of policies, guidelines, and legislation at a higher governance level, such as a national instrument with guidelines for climate-adaptive building (*NL: Landelijke maatlat groene klimaatadaptieve gebouwde omgeving*), changes in the Building Degree (*NL: Bouwbesluit*) or regional strategy for Rijnmond-Drechtsteden (*NL: voorkeursstrategie Rijnmond-Drechtsteden),* significantly impacts the practices of construction at the local level. Furthermore, decisions made at a higher system level can exert profound effects on the water system, adding complexity to the identification of required local measures. For example, the Maeslant Barrier, part of the Dutch national Delta Works, will need more frequent closure in the future. In the second half of this century, when its lifespan is reached, a decision must be made on its replacement, such as constructing a new storm surge barrier, sea lock, or permanent dam; the final decision has far-reaching consequences on the probability of flooding and the local measures to be taken for adaptation strategies in Rotterdam (Bloemen et al., 2017; Deltaprogramma, 2020; Van Veelen, 2012). Additionally, uncertainties in the rate and magnitude of sea level rise pose challenges to decision-making in coastal adaptation (Haasnoot et al., 2020). Thus, the many uncertainties and dependencies make decision-making for local climate adaptation measures complicated. Decision-makers engaged in climate adaptation are confronted with so-called deep uncertainties (Bloemen et al., 2017). Yet the urgency for climate-proof construction is increasing giving the housing challenge and changing climate (Booister, Hekman, et al., 2021; Van Der Wal, 2020).

In Netherlands, the multi-level safety framework with the layers of (1) prevention, (2) damage reduction through spatial interventions and (3) crisis management can be used to integrally implement measures that can reduce both the probability and consequences of a flooding (Bosoni et al., 2021). Physical and non-physical measures can be taken on regional level (e.g. storm surge barrier, prohibiting to build somewhere), local level (e.g. elevation of an area, structural (self-closing) flood barriers in public space, risk communication, second infrastructure for evacuation) or building level (e.g. dry- or wetproofing of building, amphibious houses, prohibit placing vulnerable infrastructure on first plinth of building). Additionally, the importance of local-scale spatial quality is highlighted as a crucial evaluation criterion, as demonstrated in a study quantifying and identifying the (dis)advantages of four strategies within the Delta Programme Rijnmond-Drechtsteden (Jeuken et al., 2011). So while at the same time measures are needed to decrease damages, preserving a direct view or connection with the water and creating new living environments are recognized as important elements in area development of unembanked areas (De Moel et al., 2014; Nilessen, 2019). Simultaneously, it is essential to conserve monuments and protected cityscapes in the unembanked areas (Rotterdams WeerWoord, 2022). Thus the location characteristics call for a tailor-made approach of measures.

As become clear by now, investing in climate-adaptive building is challenging. It involves combining multi-layer safety and spatial adaptation and thus combining safety tasks, area development processes and the conditions under which private investments can be linked to public tasks and public investments (Arcadis, 2015). Choosing the set of flood risk measures fitting for a specific location in the unembanked areas is a complex, multifaceted task. It involves not only technical aspects, but also social values and economic interests. There is a need for a transparent evaluation method of potential measures to support decision-making in spatial planning and flood risk management in the unembanked areas. Which is complicated since many stakeholders have their own interests and views on unembanked area development and the implementation of climate-adaptive measures.

Overall, there arises a need for understanding the decision-making process for implementation of flood risk measures in unembanked areas. This study will aim to contribute to the existing knowledge by looking at various evaluation methods, such as cost-benefits analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) used during the decision-making process in area development in unembanked areas (both from theory and practice) and by exploring the needs from the perspective of different stakeholders.

1.2. Background information on unembanked areas

This section will provide background information on unembanked areas in the Netherlands. Moreover, extra attention is paid to the unembanked areas in Rotterdam as this master thesis is written with support of the municipality of Rotterdam and half of all people living in unembanked areas in the Netherlands are located in Rotterdam.

1.2.1. Unembanked areas in the Netherlands

Floods have traditionally posed a threat to the Netherlands and protection from water is an important condition for living and working here. Not only the part below sea level is floodable, but also parts of the Netherlands can flood during high river discharges. As shown in Figure 4 59% of the Dutch land surface is susceptible to flooding, of which 4% of the Dutch land surface is situated outside the dike rings and, therefore, is not protected by dunes, dikes, dams or artificial structures. However, nowadays 9 million people live in this 59% of flood-prone areas and almost 70% of the Dutch GDP is earned here (Regelink et al., 2017). Given the importance of flood protection in the Netherlands, norms and standards for water safety are enshrined in the Water Act (which will be replaced by the expected Environment and Planning Act in January 2024). These norms only apply to the areas within the dike rings. Thus, for the 4% of unembanked areas, the Dutch national government has no legal obligations for flood protection and residents and users therefore bear the risk of water damage themselves (Kok et al., 2017).

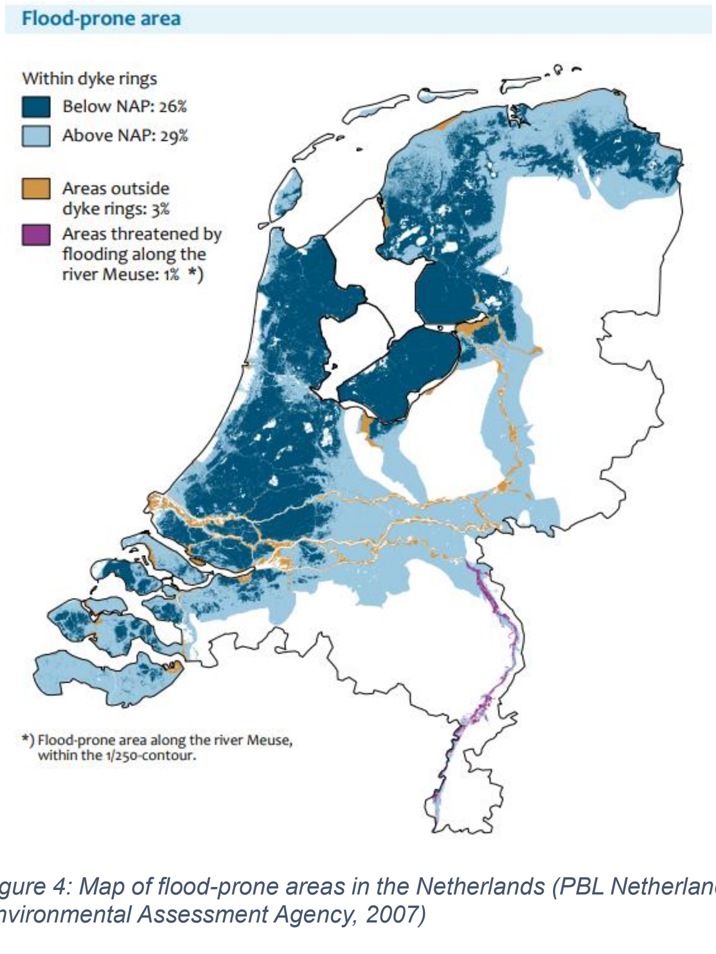

Figure 4: Map of flood-prone areas in the Netherlands (PBL Netherlands Environmental Assessment Agency, 2007)

Flood risk in unembanked areas is strongly related to water levels, height of the area, use function and design of vulnerable infrastructure (Deltaprogramma, Nieuwbouw en Herstructurering en Veiligheid, 2012). Various studies show that the risk of fatalities is generally very low in unembanked areas (Rijksoverheid, 2022; Rotterdams WeerWoord, 2023). In most cases, there is only damage involved (this can also been seen in Figure 1). Figure 5 gives a simplified visualization of the built environment in unembanked areas. The reasons why in unembanked areas there is usually only damages and a low risk of fatalities are (Deltaprogramma, Nieuwbouw en Herstructurering en Veiligheid, 2012; Rijksoverheid, 2022):

- The threat is predictable; you can see it coming.
- Flooding is usually gradual due to the relatively high elevation of the areas.
- Distance to safe area is short
- Number of people in unembanked area is relatively limited, so that in principle there are (very) good possibilities to get to safety in time

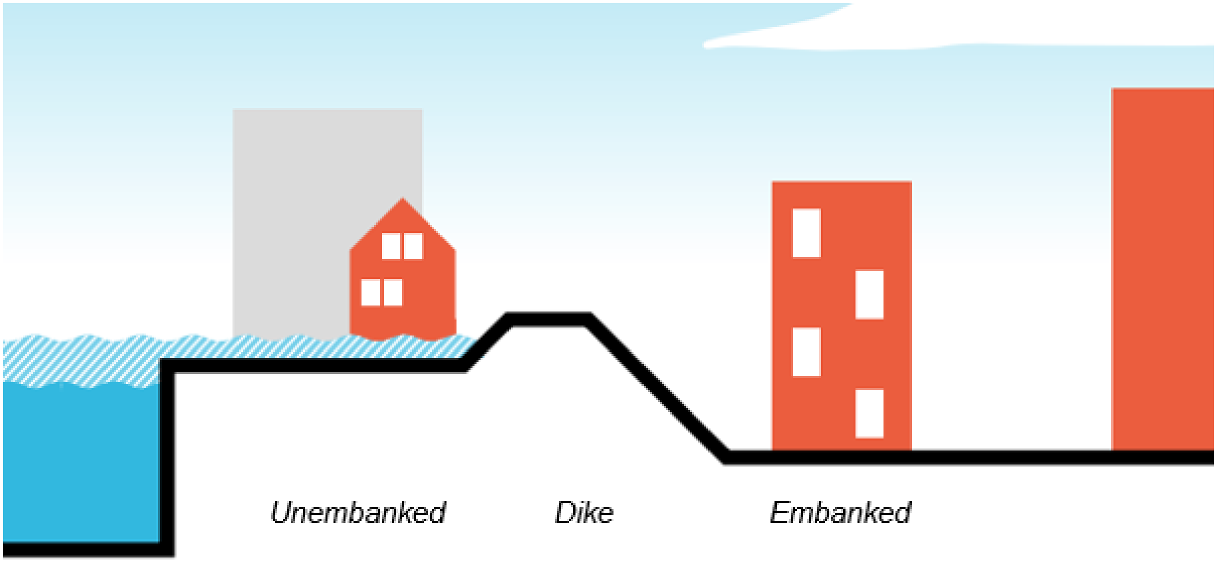

Figure 5: Simplified visualisation of cross-section unembanked and embanked area (Adapted from Rotterdams WeerWoord, 2021a)

In the Netherlands, around 115,000 people live in unembanked areas and this is expected to grow this century (Deltaprogramma, Nieuwbouw en Herstructurering en Veiligheid, 2012; TwynstraGudde & Sweco, 2023). To maintain sufficient room for river water, strike conditions apply for building in unembanked areas. As stated in the letter from former Delta Commissioner Glas (2021), it should be avoided that investments in unembanked areas will constrain the river's water storage and flow capacity, now and in the future. Further containment or exclusion of housing and other non-river-related construction activities in unembanked areas are being considered (Glas, 2021). However, a few areas, like the urban parts of Rotterdam, are exempt from these conditions based on the Large Rivers Policy Directive and the Water Decree (*NL: Beleidslijn Grote Rivieren en het Waterbesluit*). As is also stated in Glas' advice on housing construction and climate adaptation, the lower river basin has lot of unembanked, high-lying densely built-up area closely to the sea that poses little or no limitation to flow capacity and water storage. Thus this area is identified as 'exempted area' and with the creation of adaptation strategies that take into account the expected water levels, now and in the long term, it should be possible to allow urban unembanked area development and other non-harbour related activities. Figure 6 gives an overview of the amount of buildings in unembanked areas and the percentage change of the last few years in the different zones (exempted area = *vrijgesteld*, water storage = *bergend regime* and flow capacity = *stroomvoerend regime*).

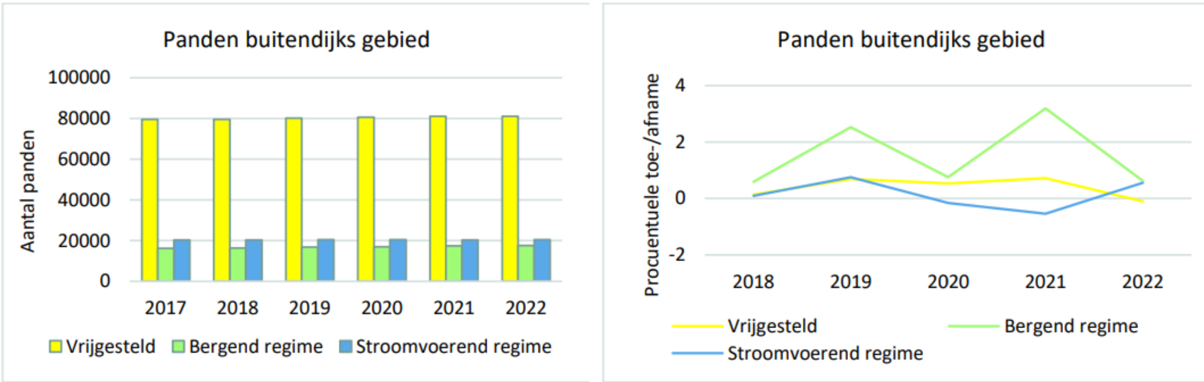

Figure 6: Overview of space use buildings in the two regimes and the exempted area (TwynstraGudde & Sweco, 2023)

Users and residents of unembanked areas are often unaware of flood risk and their own responsibility for flood damage (Deltaprogramma, Nieuwbouw en Herstructurering en Veiligheid, 2012; Nationaal Deltaprogramma Rijnmond-Drechtsteden, 2022). Before parties can draw up a joint climate adaptation strategy, they must form a shared view on the risk they find acceptable (Gebraad et al., 2018). After all, there are no set safety standards; each party makes its own risk assessment. A joint assessment framework could help this conversation (Nationaal Deltaprogramma Rijnmond-Drechtsteden, 2022).

More on how different stakeholders are involved or impacted will be explained in Chapter 5. Despite there being no national legislation for unembanked areas, certain policies for stakeholders have been drawn up and can be summarized as follows (Rijksoverheid, 2022):

- Unembanked areas are not legally protected against flooding, as these areas are in many cases originally intended for water storage and discharge.
- Residents and users themselves are responsible for taking mitigation measures and bear the risk of water damage.
- Assessment of safety, the need for additional measures (including spatial planning) and communication about water safety in unembanked areas are responsibilities of regional and local authorities.

1.2.2. Unembanked areas in Rotterdam

The previous section provided general information of unembanked areas in the Netherlands. Now, more details about unembanked areas in Rotterdam will be explained and ongoing developments related to policies and strategies will be mentioned.

The region Rijnmond-Drechtsteden, of which Rotterdam is a part, has the largest area of urban unembanked area in the Netherlands. Almost half of Rotterdam is positioned outside the dike system and more than 50,000 people live, work and recreate here (Rotterdams WeerWoord, 2021a). Although not specifically designed for unembanked areas, they benefit from the protection of the storm surge barriers i.e. the Maeslant Barrier and Hartel Barrier (see Figure 8) during high tides at sea as they close when a certain water level is reached. Several times a year, the operational high-water team of the municipality of Rotterdam rushes out to close the low unembanked quays and tow away cars, see Figure 7 (Nationaal Deltaprogramma Rijnmond-Drechtsteden, 2022).

Figure 7: Closure of road in unembanked area in Rotterdam during high water event on 23-11-2023 (Photo taking by author)

In an internal document used for advising colleagues, and as mentioned before, it is indicated that due to the lack of dikes, unembanked areas flood faster than the embanked areas (Team Hoogwater, Redeneerlijn buitendijks bouwen en beheren, 2023). Moreover, flooding in this area mainly causes damage and does not lead to danger to life. The unembanked areas are suitable for living and working, provided the areas are designed in a climate-adaptive way (Team Hoogwater, Redeneerlijn buitendijks bouwen en beheren, 2023).

However, the advantage of unembanked areas, traditionally the highest places in the city, is that the water can never get as deep and unexpected as in the low areas behind the dike (should a dike breach occur). Moreover, building in urban unembanked areas fits in with two main choices from the Vision on Spatial Planning and Environment (*NL: Omgevingsvisie Rotterdam)* (Team Hoogwater, Redeneerlijn buitendijks bouwen en beheren, 2023):

- Rotterdam is working on pleasant living in the delta.
- Rotterdam is going to urbanise and connect.

In Rotterdam, the unembanked area consists of the entire port area, the redeveloped old city harbours, such as Katendrecht, and parts of even older inhabited areas such as Noordereiland and Scheepvaartkwartier. Since the unembanked areas have been developed over decades, these areas vary in height. Figure 8 gives an overview of the unembanked areas in Rotterdam and shows relevant flood defences and their safety standards. Next to that, Figure 8 shows the different issue levels (*NL: uitgiftepeilen*) applied to different areas in Rotterdam. This is one of the measures the municipality has officially adopted in their policies from 2018 onwards.

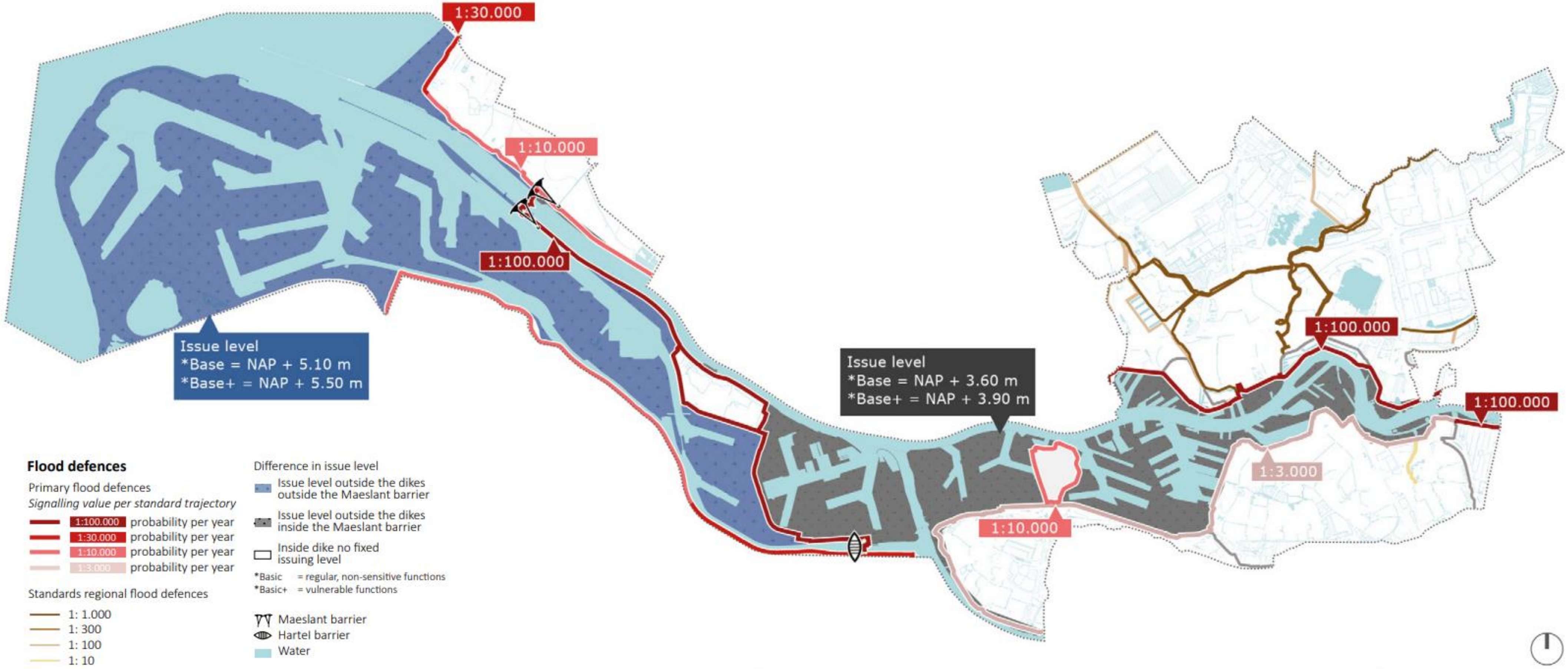

Figure 8: Flood defences and unembanked areas in Rotterdam (data: Waterveiligheidsportaal - Water safey standards for flood defences are established in law. Issue levels are prescribed in the Recalibatrion policy (ground) issue levels in the unembanked areas City of Rotterdam (2018), source figure: Rotterdam Weatherwise, 2023)

Existing urban areas, such as Noordereiland or Kop van Feijenoord, where no major developments are taking place, also need protection. Elevating or flood-proofing existing buildings, particularly monuments and historical heritage, is a complex task, as the option of elevation involves lifting structures, which is both very expensive and often unrealistic, posing a risk of damage to original elements. With existing buildings, water is therefore more likely to be held back by interventions in public spaces, combined with measures of crisis management. As you can see, choosing the most appropriate combination of measures requires a tailor-made adaptation strategy for each area. An important step in protecting Rotterdam's unembanked areas is therefore the development of 'area-based adaptation strategies'.

Research from 2012 in an unembanked inner-city area of Rotterdam revealed that barriers to integrating climate adaptation measures arise due to fragmented water-safety policy and hierarchical governance arrangements, sparking concerns about social justice implications (Kokx & Spit, 2012). But the city has responded to this by launching adaptation strategies for all unembanked areas. For the port areas, strategies have already been drawn up in the period 2015-2021, and the municipality is now working on strategies for urban areas with Kop van Feijenoord being the first, see Figure 9 (Rotterdams WeerWoord, 2021a).

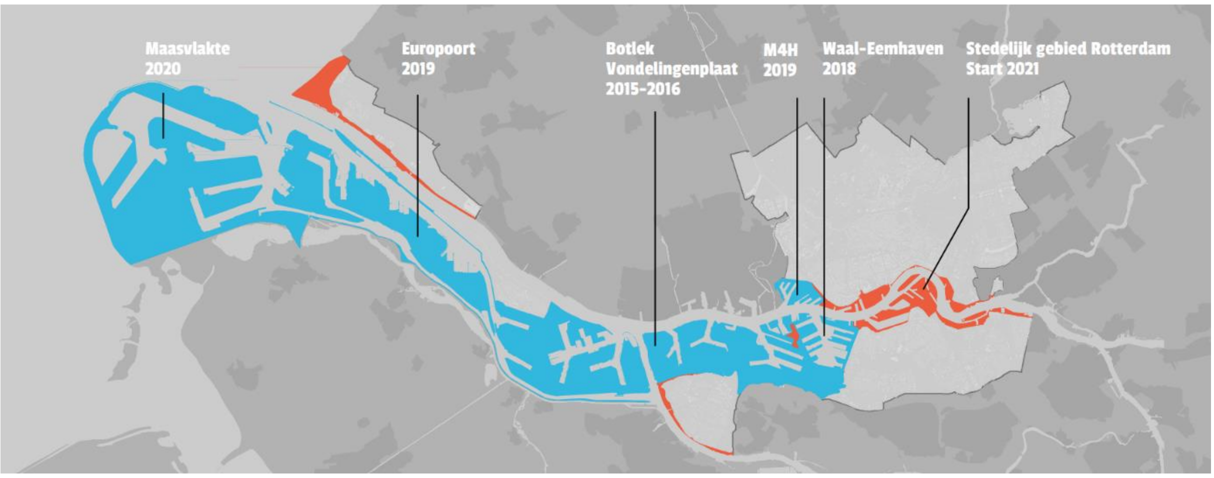

Figure 9: Overview of unembanked areas in Rotterdam for which an adaptation strategy has been formulated (blue) or is yet to be formulated (red) (Rotterdams WeerWoord, 2021a)

The adaptation strategies made by Royal HaskoningDHV for the port areas of Rotterdam are finished and clarify how they gradually will adapt to increasing flood risk. The adaptation strategies have been used as inspiration for this research and are used for relevant background information. When reading the online version of this thesis, the adaptation strategies can be found using the forwarding links:

- Pilot Botlek Waterveiligheid (2016)
- Strategische Adaptatieagenda Buitendijks (2017)
- Waterveiligheid Botlek en de Vondelingenplaat (2017)
- Waterveiligheid Waal-Eemhaven (2018)
- Waterveiligheid Merwe-Vierhavens (2019)
- Waterveiligheid Europoort (2020)
- Waterveiligheid Maasvlakte (2021)
- Overstromingsrisico's overige gebieden (2021)
- Een waterveilige Rotterdamse haven (2022)

1.3. Knowledge gaps

Based on the first literature review and from exploratory interviews with stakeholders in water management and area development, two knowledge gaps clearly emerged.

The first knowledge gap is about how it is currently decided on a local and building level which flood risk measures will be implemented during area (re)developments in unembanked areas. Although using CBAs in flood risk management and spatial planning is not new, (scientific) literature on CBAs specifically focused on unembanked areas is scarce. Moreover, there are no CBAs for unembanked areas that consider non-monetary effects, while literature clearly shows that aspects such as quality of landscape, quality of nature, stress for floods and cultural heritage are important to include in decision-making for flood risk management in area developments. Literature indicates that it can be difficult to properly map or monetise social effects, but still stress the importance to incorporate these aspects. Of course, other evaluation methods are also possible, such as cost-effectiveness analysis (CEA), multi-criteria analysis (MCA) or impact assessments (IA). However, knowledge is lacking on how all (social) costs and benefits are taking into account in the decision-making process for local flood risk measures in unembanked areas.

The second knowledge gap relates to impact on and involvement of stakeholders. It shows that the multi-level safety concept is suitable to apply in unembanked areas since investing in layer 2 (damage reduction through spatial planning) and 3 (crisis management) can pay off for climate-adaptive building. However, investing in the second layer (e.g. elevating sites/buildings, dry- and waterproof building) and third layer (e.g. evacuation plans and emergency measures) is more complex than investing in layer 1, as it involves more and different parties like real estate developers and home-owners. Responsibilities in unembanked areas are legally different from within the dike-rings and this is something that stakeholders struggle with. For instance, if a flood wall is installed by the municipality on the quay in public space to prevent against high water, does the liability for damage in case of failure shifts to the municipality, or does it remain with the residents who choose to live in the unembanked areas at own risk, despite likely assuming protection due to the installation of that flood wall? It is even more complicated as stakeholders have a false, limited or non-existing flood risk awareness in unembanked areas, if they are even aware of unembanked areas at all. Thus, knowledge is lacking on how stakeholders have influence or are impacted by implementation for local flood risk measures in unembanked areas, and what their needs are for the decision-making process.

1.4. Societal relevance

To start, the rising sea levels and more frequent extreme weather conditions are putting cities under pressure and ask for adaptation to the changing climate. Given that new buildings are expected to last at least 50-100+ years, it is of societal importance to construct them with climate adaptability in mind to prevent future generations from suffering the consequences of what we build today. Implementing flood risk measures does not only have societal value to prevent damage and fatalities, but it also of societal importance to preventing passing on consequences of climate change to future generations.

Second, climate change impacts numerous stakeholders. Climate-adaptive building is a relatively new topic, and many parties are still in the developmental and exploratory phases of figuring out how to address it. Preliminary discussions with stakeholders have already revealed unclarities in responsibilities for climate-adaptive investments. Providing insight into the need for decision-making on local adaptation measures holds societal value.

Third, it is crucial that once the decision to build in unembanked areas is made, the implementation of local flood measures can contribute to the living environment and spatial quality of the area. Beyond guaranteeing safety against floods, it holds societal value to design unembanked areas attractively by considering quality of nature, landscape, and integration with the existing built environment.

Fourth, many parties are unfamiliar with what unembanked areas are or have a poor understanding of what it entails. Therefore, it is beneficial for more parties to become aware of unembanked areas and be correctly informed about the risks. This can lead to a shift in which it becomes more acceptable for certain areas to flood every once in a while (provided the area is designed accordingly), as opposed to the current approach in flood risk management of trying to keep the water out preventively as much as possible. Collaboration between parties is essential to arrive at suitable solutions. This study includes several interviews and meetings with stakeholders, thus emphasizing the creation of awareness and the provision of information, which ultimately has social value.

Lastly, climate change can have a significant impact on social justice. It often disproportionately affects vulnerable communities such as low-income and minority groups, leading to inequality. Residents and users in unembanked areas are responsible for protecting against water damage themselves. Currently, it is not possible for individuals to obtain insurance in unembanked areas. This raises questions about the distribution of costs and benefits for investments in unembanked areas. The municipality chooses to develop these areas and incurs costs for the design of public spaces, developers, and housing corporations incur costs for climate-adaptive construction, but subsequently pass these costs on to future buyers and users, while thus at the same time they cannot get insurance. Social justice requires a fair distribution between costs and benefits, and this research can contribute providing more insights in this.

1.5. Scientific relevance

To begin with, there is little literature specifically focusing on unembanked areas as the term is known in Dutch context. Various reports from entities like Rijkswaterstaat, water boards, and the Delta Programme are engaged in climate adaptation in flood risk management, but these reports only briefly mention the unembanked areas or provide a general description in which the need for adaptation strategies is addressed. Moreover, scientific research that primarily centres on spatial planning of unembanked areas is very scarce. This research can thus contribute to current knowledge on unembanked areas and aims to understand how decision-making for local flood risk measures in these areas is done.

Furthermore, the use of various evaluation methods like cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) in flood risk management and area development is not new. Nevertheless, scientific literature regarding evaluation tools for flood risk measures in unembanked areas is lacking. Moreover, the term "cost and benefit analysis" is broadly interpreted and used in various ways in research. Therefore, this study adds something valuable by shedding light on the different evaluation methods used to support decision-making on flood risk measures in unembanked areas as this will be examined through literature and practical cases. Its scientific worth lies in compiling this information to provide guidance on how decision-making at a local level can be enhanced.

Finally, the limited available CBAs for unembanked areas fail to consider distributional effects or to monetize social values, if they are included at all. Most studies only focus on the benefits from water safety perspective, but for an entity like the municipality of Rotterdam, it is vital to incorporate other social aspects and the current built environment into their decision-making process. However, social aspects such as spatial quality, the stress associated with potential floods, or cultural heritage are not often not included. Thereby, elevating an area or building may be the most cost-effective measure (as some CBAs and CEAs now show), but are not feasible or desirable in practice. The strength of the evaluation method in supporting realistic decision-making thus weakens, while stakeholders like the municipality have a very strong interest in grounded arguments for their choices. Therefore, this research contributes by examining several evaluation methods, how they have been used in theory and practice and its applicability in supporting decision-making on local flood risk measures within a certain area.

1.6. Research objective

The research objective is as follows:

To gain a better understanding of the decision-making process for local flood risk measures in area development in unembanked areas

This study aims to contribute to providing a better understanding of how decision-making for local flood risk measures in unembanked works. (Scientific) literature specifically on implementing flood risk measures in unembanked areas is scarce. This study therefore aims to bundle and describe in a well-organised way how different evaluation methods for flood risk measures in unembanked areas are currently used through a literature review, by looking at practical examples, and by examining the impact on and needs of stakeholders. Based on the knowledge gained throughout the research, this should ultimately lead to useful insights and recommendations for decision makers involved in the implementation of flood risk measures during development in unembanked areas.

1.7. Research questions

Based on the research objective and preliminary research, the following research questions have been formulated. The main research question is as follows:

What evaluation methods are appropriate to use in the decision-making process for local flood risk measures in area development in unembanked areas, and what are the needs of stakeholders regarding the decision-making process?

The knowledge necessary to answer the main research question will be gained by answering several sub-questions derived from the main question. The sub-questions are as follows:

SQ1: What evaluation methods are commonly used in flood risk management, and how do these various evaluation methods facilitate the decision-making process in area development in unembanked areas?

SQ2: What decision-making methods have been used in recent projects in unembanked areas, and what can be learned from these practical examples?

SQ3: What are the conditions and needs regarding the decision-making process of local flood risk measures in unembanked areas from the perspective of various stakeholders?

1.8. Report outline

This section contains the reading guide for this report. First, Chapter 1 gives an introduction to the problem and motivation for this research. Following this, Chapter 2 details the research approach and explains how literature review, interviews, and case studies have been employed in this study. Next, Chapter 3 describes the theoretical background for flood risk management by zooming in on relevant frameworks and concepts, various evaluation tools and previous studies done for flood risk management in unembanked areas. Chapter 4 will describe the decision-making process of real-world examples while looking at the different evaluation methods used and what lessons can be drawn from practice. Subsequently, Chapter 5 will describe which, how and why stakeholders are involved or affected in by implementing flood risk measures in unembanked and it will be explained what their needs are. In Chapter 6 the conclusion and answers to the research questions will be given, followed by the discussion and recommendations in Chapters 7.

2

RESEARCH DESIGN

2.1. Research scope and assumptions

This research focuses on climate-adaptive building in unembanked areas. This section will explain what the research scope is and what assumptions have been made in order have a feasible graduation project within the set time frame.

First of all, this study is based on the fact that there are many plans to develop in unembanked areas in the coming years. As mentioned, according to the *Redeneerlijn Buitendijks Bouwen* (2023), urban unembanked areas are attractive locations to build and, when considering adaptive measures for the future climate, could be safely designed and constructed for living and working purposes. Nevertheless, a lot of discussion is going on in the field of water management and spatial planning (e.g. *Kamerbrief Water en Bodem sturend* and expected new Spatial Planning and Environmental Act (*Omgevingswet*) on 1st of January 2024 replacing the current Water Act) whether where and how to build. The debate whether or not to build in unembanked areas at all, which is often fuelled with mislead information or poor understanding, is left aside in this research. It is assumed that the plans for area development in the unembanked areas will continue and this is taking as a basis for this research.

Moreover, climate adaptation goes beyond considering floods. Measures against other consequences of the changing climate such as extreme heat, drought, (heavy) precipitation are not included in this study. For unembanked areas, sea level rise and increased river discharges pose the greatest risk, so this was taken as the starting point for this study.

Additionally, this research will only consider a few evaluation methods, while there are, of course, more possibilities. Based on preliminary research, it was found that incorporating social values is crucial during developments in unembanked areas, and considering the ongoing discussions about cost and benefit distribution of climate-adaptive measures among stakeholders, conducting a social cost-benefit analysis (CBA), or at least a set-up, was the original goal of this research. CBA allows the inclusion of all costs and benefits, and it is possible to add distribution effects, indicating how costs and benefits are divided among stakeholders. However, limitations of the CBA were encountered during the research, primarily the lack of available data for social effects. As a result, attention was also given to other evaluation methods such as multi-criteria analysis (MCA), cost-effectiveness analysis (CEA), and impact assessments (IA). Nevertheless, throughout the report, it is evident that there is an strong emphasis on the CBA.

Furthermore, while looking at practical examples, only area (re)developments where there is a mix of living and working were considered. This means that unembanked areas where only industrial activities take place, e.g. Botlek and Maasvlakte in the port of Rotterdam, are not been taking into account for real-world examples. National and regional decisions, for example on the Measlant barrier, have a major impact on flood protection in unembanked areas of Rotterdam. However, this type of developments are mentioned to address the complexity of decision-making on local measures, but this study primarily focuses only on flood risk measures that fall within an area plan, i.e. measures that are taken at district or building level.

Thereby, the focus of this study is on the Dutch context given the specific legislation for unembanked areas. In the Netherlands, a clear distinction is made between '*binnendijks*' en '*buitendijks*' subsequently meaning areas inside the dike-rings or areas outside the dike-rings, so called unembanked. Therefore this term have been employed for the search in (academic) literature. However, in order to still learn from practice, Copenhagen and Hamburg were chosen for case studies as they are often cited as international examples of how to deal with flood risks from the sea and also have unembanked areas (although they might use other terms in their legal system or may not have such a clear distinction as in the Netherlands).

For the other case study areas, Rotterdam, Zwolle and Vlaardingen were selected for lessons learned from practice. Despite there being more examples of area development in unembanked areas like in Dordrecht and Hellevoetsluis, it was decided not to add more case studies given the timeframe of this study. Although these cities were not examined as case studies, knowledge about the developments in their unembanked areas was still gained and used in this research through (bilateral) meetings between the municipalities of Rotterdam and Dordrecht, the *DPRD Platform Buitendijks* (including a field visit in Hellevoetsluis) and other interactions.

Finally, only qualitative research methods are used to better understand the decision-making process for designing unembanked areas. This research focuses on the methodologies supporting decision-making in area development in unembanked areas and quantitative analysis such as a sample calculation of a cost-benefit analysis or cost-effectiveness are beyond the scope of this study. Therefore, the study will hardly discuss quantitative data collection necessary for various evaluation methods or flood damage models. Ultimately, the aim is to use the results of the literature review, lessons learned from practice, influence of and impact on stakeholders to understand decision-making process in area development in unembanked areas.

2.2. Research approach

The research was carried out for Delft University of Technology with assistance of the municipality of Rotterdam. The municipality provided support in the form of sharing in-house knowledge and expert experience on water management and spatial planning in urban areas and unembanked areas. In order to answer the research question, a comprehensive methodology was followed, combining various research methods, see Figure 10 for an overview.

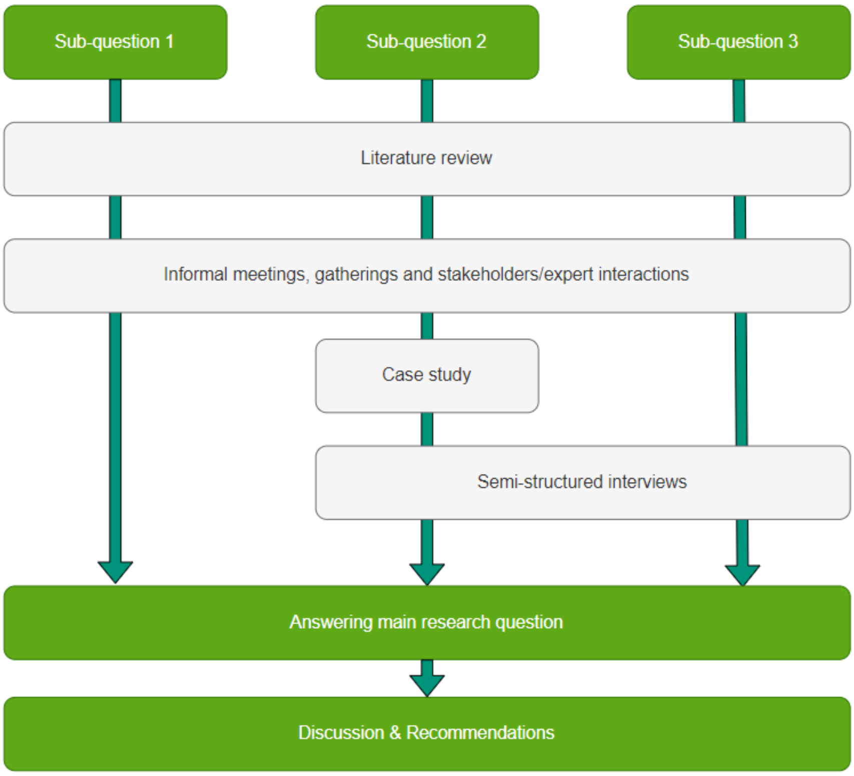

Figure 10: Research structure and methods used (Authors's image)

2.3. Literature review

The first chosen method in this research is a literature review. It is crucial to build and relate research to existing knowledge (Snyder, 2019). For this research, existing literature on flood risk management in unembanked areas is reviewed. The literature was used to find out more about the unembanked areas themselves, what they entail, what kind of risks there are, how these risks are dealt with, what kind of adaptation measures are possible, and how evaluation methods exist for decision what the most suitable measures are to implement in an area.

For the literature review, Scopus and Google Scholar are used as search engines for academic papers. When looking for academic studies, the combination of the search terms like 'flood risk management', 'cost-benefit analysis', 'unembanked areas', 'spatial planning' are used. This was followed up by back-referencing relevant sources cited by the found literature. In this way, a combination of searches in databases and backward snowballing is performed. In addition, Google was used to find reports on climate-adaptation in cities and policies and legislation on unembanked areas from, for example, the municipality Rotterdam, the Delta Programme, national government etc.

For the first sub-question, literature has been used to learn more on decision-making in flood risk management. From the preliminary research for this thesis, it had become clear that cost-benefit analysis are already widely used in water management and area development projects. However, academic research focused specially on how to deal with flood risk in unembanked areas is very scarce. Therefore, flood risk management has been considered in a broader sense and literature where unembanked areas where mentioned as a sub component are also reviewed. Therefore, theories, frameworks and evaluation methods that are useful for unembanked areas have been reviewed to get at a better understanding of the context and decision-making for local measures. This involved examining used evaluation methods and their flaws that have been used to support decision-making in unembanked areas.

Additionally, for the second sub-question on lessons learned from practice, literature is used to find more information on the chosen case study areas. Literature on background information was used to support and confirm the information received from interviewees. For the third sub-question, the literature was used to examine the role of stakeholders in flood risk management and area development in unembanked areas.

2.4. Expert and stakeholders interactions

This research made extensive use of unstructured interviews and interactions with experts and stakeholders. These included one-to-one interviews with people working in water management, climate adaptation, area development and financial sector. In addition, many meetings, conferences and gatherings related to the built environment and climate adaptation were attended, often focused on how can be prepared for the changing climate and the consequences it has on the built environment. These interactions included experts meetings with people within and outside the municipality of Rotterdam. All these forms of interaction with stakeholders and experts contributed to gathering background information, helped to gain a good understanding of the flood risks in unembanked areas and gave insight in the ongoing developments and discussions on climate-adaptation in the built environment. Moreover, it involved interactions with an expert in CBAs, experts engaged in the adaptation strategies of Rotterdam, and stakeholders participating in area development in unembanked areas, all of whom contributed to understanding decision-making processes for unembanked area development. All in all, it ensured that the problem and context is well understood and that the most up-to-date information was used.

The many interactions with stakeholders and experts related to various sectors are partly made possible by municipality of Rotterdam and the Red&Blue Program. The municipality's extensive network opened many doors for contacts, both inside and outside the organisation. It made it possible to speak to many experts and to attend meetings, conferences and other kind of gatherings. The network of the Red&Blue program, a transdisciplinary knowledge agenda for integrated real estate and infrastructure climate risk management in the Dutch delta, of which most members of the graduation committee are involved in, supported in knowledge gathering. All the interactions helped in retrieving valuables insights and in-depth knowledge and provided primary data such as experiences and qualitative information, which helped to enrich the research and provide real-world context. It also provided a diverse perspective on the problem, allowing it to be seen from different angles. The overview of all interactions can be seen in Table 10 in Appendix A – Overview expert interactions.

2.5. Case studies

To learn how the decision-making process works on what flood risk measures to implement in area development and what methods have been used to evaluate possible measures, case studies will be used. This was done to complement the preceding literature review by observing how theory translates into practice. In addition to delineating the pros and cons of decision-making methods based on theory, analysing real-world examples can yield fresh insights into preferred and most effective evaluation methods.

As mentioned earlier, Copenhagen and Hamburg are frequently cited as international examples of how to deal with flood risk coming from the sea in urban environments. Contact has been made with these cities through the network of the municipality of Rotterdam. As they claim themselves; '*Hamburg HafenCity is Europe's largest inner-city urban development area blueprint for the new European city on the waterfront*.' As there are many similarities between the characteristics of the unembanked areas of Hamburg and Rotterdam, this is an interesting area to include in the study. For Copenhagen, the interview revealed that they are working on a regional adaptation strategy in cooperation with other municipalities. The municipality of Dragør plays an interesting role given its location near the sea and high risk awareness among residents. As they fall within the same regional adaptation strategy, they have been handled as a single case study. It should be noted, however, that Copenhagen and Dragør differ slightly from the other case studies in that they are considered from a regional perspective, whereas the original focus of this study is primarily on local measures in area development. Since it nevertheless provided interesting insights and to demonstrate how evaluation methods and decision-making works on a larger scale, it is deliberately chosen to include this case study in this research.

Apart from the learning from international examples, Rotterdam, Zwolle and Vlaardingen were chosen as case study areas. Rotterdam is chosen since this research is executed with support of the municipality and half of the Dutch citizens living in unembanked areas are located in Rotterdam. Moreover, during the research period at the municipality, it was possible to be part of the team working on the recalibration of the issue levels. The issue level is a measure that applies to all unembanked areas in Rotterdam, and a lot of extensive research has been conducted in this regard.

Moreover, several adaptation strategies are made or are being developed for the unembanked areas in Rotterdam. Apart from cross-borders measure like the issue level that impacts every Rotterdam area development, one of the individual adaptation plans will be particularly examined closely. For this, Merwe-Vierhaven (M4H), is chosen as case study area. This is an interesting area, as it will be transformed from a port area into a new function for living, working, education and recreation. Merwehaven, part of M4H, is going to be turned into an innovative urban district with attention to historic past and the original structure of old city harbour. In the first phase, 2,500 new homes are planned for Merwehaven and a total of about 5,100 homes are expected until 2040 in the whole M4H, see Figure 3. In doing so, the Masterplan Merwehavens describes that M4H will be used as a testing ground with plenty of room for experimenting and learning e.g. tidal parks, space for floating housing and developing M4H as a resilient climate-adaptive system (Gemeente Rotterdam, 2023). Given that an tailor-made adaptation strategy is in place and a Masterplan has been developed, there is a wealth of information on how decisions have been made regarding flood risk management while taking into account spatial qualities of the area. For this case study, also a meeting has been held with an employee of Royal HaskoningDHV and author of the adaptation strategy for M4H. This can be seen in Table 10 in Appendix A – Overview expert interactions

Finally, Zwolle was chosen since it was preceded by a knowledge exchange with the municipality of Rotterdam and field visit to their area development projects in unembanked areas. One of the area developments in Zwolle's unembanked areas has already been completed and another was in the preparatory phase. Therefore, this is a fascinating area to include. Vlaardingen was chosen next since, like Rotterdam and Hamburg, it has many (old) port characteristics. In addition, during high tides water in Vlaardingen stands on the quays every few years, so the urgency of flood protection measures is very high. While deciding how to deal with the increasing flood risks in Vlaardingen, attention must be paid to preserve the cultural-historical values in the area and a direct connection to the water is argued to have high social value. Contact was made with several people working on this area development in Vlaardingen after a Delta Programme conference and via email.

2.6. Semi-structured interviews

Semi-structured interviews were used for answering sub-question 2 and 3. These semi-structured interviews differed from other expert and stakeholder interactions as they had more specific objectives to contribute to a particular sub-question. The other interactions, on the other hand, generally aided in a better understanding of unembanked area development and decision-making for climate-adaptive construction. Semi-structured interviews provided a way to conduct in-depth and open interviews, striking a balance between focused questions and at the same time allowing room for the interviewee's own input.

2.6.1. Semi-structured interviews: lessons learned from practice

For the real-world examples, via different channels contact was made with experts involved in climate adaptation in the unembanked areas in the chosen case study areas. For privacy reasons, the personal name of the interviewee is left aside. Apart from this semi-structured interviews, for lessons learned from practice in Rotterdam, weekly meetings and additional interviews and workshops with e.g. asset managers were attended. This was made possible as the opportunity arose to be part of the team working on the evaluation and recalibration of the issue level policy. Although these meetings provided useful insights, they have not been included in Table 1 because they were repetitive meetings where not primarily focused on this thesis.

Table 1: Interviews for lessons learned from practice

No.	Date	City and Country	Organisation	Function
1	26-06-23	Copenhagen, Denmark	Municipality	Special consultant in area of climate change
2	28-06-23	Vlaardingen, the Netherlands	Management Consultant	Project manager
3	02-08-23	Hamburg, Germany	HafenCity Hamburg GmbH	Project manager
4	15-08-23	Zwolle, the Netherlands	Municipality	Strategic advisor water and spatial adaptation
5	05-10-23	Dragør, Denmark	Municipality	Project manager climate resilience and coastal protection

2.6.2. Semi-structured interviews: risk governance

Furthermore, semi-structured interview were used to answer sub-question 3. These interviews were used to explore stakeholders interests and views on implementing flood measures in unembanked areas and to look at the conditions and needs from their perspective. To cover as many stakeholders as possible, interviews were with both public and private parties like insurers, banks, real estate developer, Rijkswaterstaat, Veiligheidsregio and several employees of the municipality. There has been interactions with various water boards at multiple occasions. In addition, contact was made via e-mail with the Hoogheemraadschap van Delfland, the water board that borders M4H. Questions were asked via email and it turned out that a follow-up interview was irrelevant given the role of water boards in unembanked areas. Finally, given the time, it was not possible to schedule more interviews with citizens, housing associations, the province, or other relevant stakeholders.

Table 2: Interviews with stakeholders for risk governance

No.	Date	Organisation	Function
1	06-09-2023	Municipality of Rotterdam	Project manager of M4H
2	13-09-2023	Municipality of Rotterdam	Planning economist
3	13-09-2023	ABN AMRO	Risk manager for climate risk and sustainability
4	14-9-2023	Rijkswaterstaat	Advisor network development and vision
5	14-09-2023	Achmea	Senior manager climate change and international
6	20-09-2023	Rabobank	Advisor to the Board from Sustainability Department and Chair of NVB Working Group Climate
7	25-09-2023	Verbond van Verzekeraars	Policy advisor climate change
8	25-09-2023	Veiligheidsregio Rotterdam-Rijnmond	Policy advisor safe living environment
9	11-10-2023	Heijmans	Commercial region manager real estate
10	16-10-2023	Municipality of Rotterdam	Asset manager on validation social values

3

THEORETICAL BACKGROUND

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3.1. Introduction

A solid grasp of existing literature is crucial for effective research. However, scientific literature specifically on unembanked areas, as how the term is used in Dutch context, is scarce and often not up to date. For example, when using the combination of ‘flood risk management’ and ‘unembanked areas’ in the Scopus search engine only 8 documents come forward, which all are older than 2018. Also, searching on Scopus with the combination of ‘cost-benefit analysis’ or ‘decision making’ and ‘unembanked areas’ even give zero results. Research such as Van Vliet and Aerts (2015) paper on how adaptive measures in unembanked areas fit within the policies, laws and regulations of Rotterdam, Veerbeek and Gersonius, (2010) on flood impact assessment for Rotterdam’s unembanked area and Kokx and Spit (2012) on stakeholder support for adaptive measures in Rotterdam become less relevant nowadays since a lot have changed over time. In contrast, more (scientific) literature can be found on general flood risk management concepts and approaches and decision-making methods in urban developments in low-lying coastal areas. Therefore, this chapter will look in a broader perspective to literature on the decision-making process for flood risk measures.

While various evaluation methods, such as CBA, are recognized for their widespread application in flood risk management and spatial planning, there are limited examples specifically for unembanked areas. Despite the scarce availability, insights can be drawn from the adaptation strategies made for the port areas of Rotterdam and certain graduation projects. Using the TU Delft education repository and Utrecht University student theses repository yields several master theses concentrating on flood risk management in unembanked areas, often with a case study in which some form of cost-benefit analysis is applied (Cossu, 2023; Dam, 2021; Knulst, 2017; Veenman, 2019; Wolthuis, 2011). In their studies, for benefits they most of the time only consider the effect on reduction in flood risk, but other effects of adaptation measures are not considered.

Nevertheless, the previous paragraphs give a first indication on how scarce available scientific literature is on decision-making process for unembanked area development. Therefore, next to the limited available research on unembanked areas, this chapter also reviews some more general approaches and concepts in flood risk management that are relevant or related to decision-making on measures in unembanked areas. This chapter contributes to answering the first sub question: *What evaluation methods are commonly used in flood risk management, and how do these various evaluation methods facilitate the decision-making process in area development in unembanked areas?*

3.2. Flood risk management

Flood risk management encompasses a diverse range of issues and tasks, spanning from forecasting flood hazards to evaluating their societal implications, and implementing measures and instruments for reducing the risks involved (Schanze et al., 2007). Three main tasks with specific components can be used for structuring the management activities: risk analysis, risk assessment and risk reduction. Risk analysis involves examining past, present, and future flood risks, while risk assessment focuses on how these risks are perceived and evaluated, and risk reduction is dedicated to implementing interventions with the potential to decrease the identified risks. Flood risk management is a dynamic decision-making and developmental process involving various stakeholders from different fields at different levels (Schanze et al., 2007). It is influenced by political, administrative, planning and cultural systems in place. Figure 11 provides a basic framework of flood risk management.

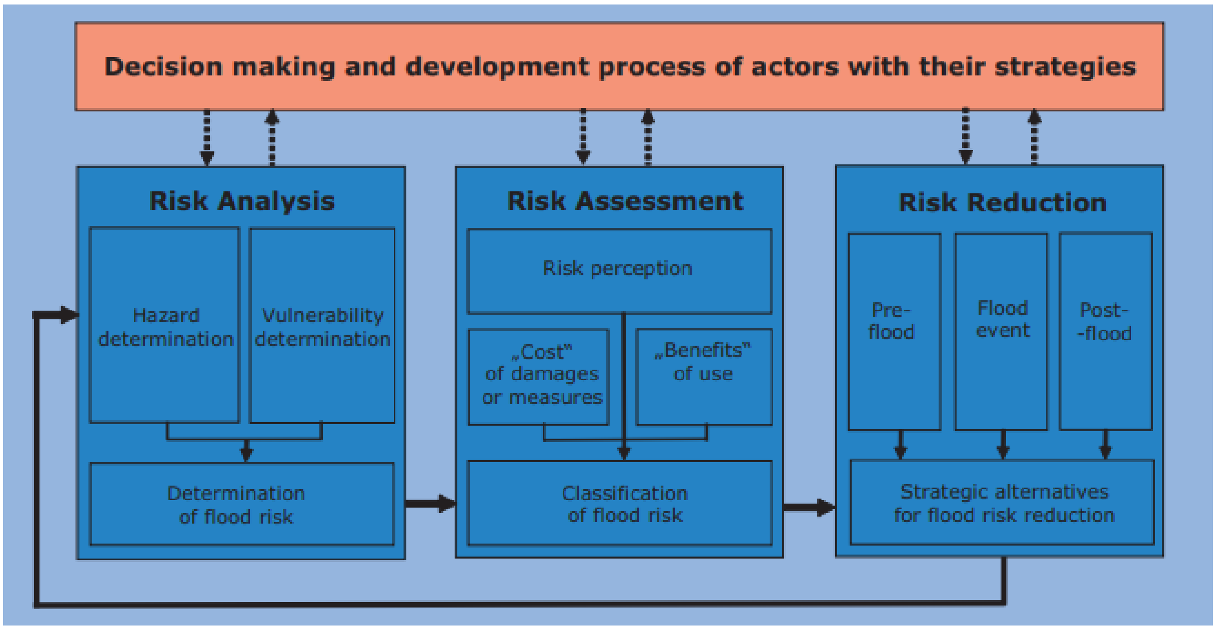


Figure 11: Basic framework of flood risk management (Schanze et al., 2007)

Commonly, risk-based approaches are used to assess flood risk and evaluate the cost-effectiveness of risk mitigation measures (Lendering, 2018). Although different disciplines have varied definitions of risk, herein risk refers to both the possible consequences of floods and the probability of their occurrence. It indicates which consequences can occur with what probability. Evaluating flood risk can be helpful with deciding whether the level of safety provided is sufficient: in other words, whether there is an acceptable risk (Kok et al., 2017).

Flood risk is defined as follows:

$$Flood\ risk = probability\ of\ flood\ \times consequences$$

The probability of a flood is the failure probability of various components of a flood defence system and the consequences stem from exposure to various elements such as people, buildings, businesses, and infrastructure, as well as their respective vulnerability (i.e., engineering, economic, social, and environmental) (Lendering, 2018; Klijn et al., 2015; Kok et al., 2017). According to this definition, risk reduction can be accomplished by decreasing the likelihood of a flood or the possible consequences of a flood.

Consequences

To begin with, multiple categories of consequences have been identified for the assessment of impacts. These include casualties, economic damage, societal disruption, environmental damage, damage to culture, and damage to nature (Deltares, 2018; Huizinga et al., 2011; Vergouwe, 2016). The economic impact of a flood includes direct damage to capital assets such as houses, infrastructure, personal belongings and direct economic damage due to loss of business in the affected area (Deltares, 2018; Vergouwe, 2016). Moreover, indirect economic damage includes losses in supplying and consuming businesses outside the flooded area, or, for example, travel time loss due to the disruption of (rail)roads in the flooded area (Deltares, 2018).

Societal disruption is the extent to which people experience physical, social, or emotional distress due to a high-water event causing a function to fail. Those affected by societal disruption can be both in the embanked as well as in the unembanked areas. Huizinga et al. (2011) have developed a methodology to quantify societal disruption in unembanked areas. The method suggests that four factors are crucial for societal disruption:

- Size of the affected area (number of people)
- Societal disruption severity factor: this factor indicates the level of distress caused by the failure of a function. The greater the societal disruption severity factor, the more significant the disruption resulting from the function's failure. The estimation of the societal disruption severity factor is based on expert judgment and has a value between 0.1 and 1;
- The duration of flooding in an area;
- The depth of water occurring in the flooded area.

However, the risk analysis methodology developed by Huizinga et al. (2011) does not address the quantification of damage to nature (assuming nature in unembanked areas is robust against high water), cultural (historical) damage (assuming it is less relevant in unembanked areas due to policy delineation that the method is only applicable to newly developed areas), and environmental damage (assumed to be part of the permitting process related to the use of hazardous substances and not within the domain of water safety).

Following, the number of fatalities caused by a flood is calculated on the basis of the number of people living in the area combined with the flood characteristics like speed and rise rate of the water (Deltares, 2018; Vergouwe, 2016). The effectiveness of preventive evacuation depends on the predictability of flooding, capacity of infrastructure and the circumstances in which the evacuation has to take place, such as weather conditions and general panic (Vergouwe, 2016). In the Netherlands, damages and fatalities are mostly determined with the method of HIS-SSM (*NL: Hoogwater Informatie Systeem – Schade en Slachtoffer Module*) (Deltares, 2018).

Probability of flood

For unembanked areas, the probability that an area will flood, is determined primarily by the probability of occurrence of higher water levels (and waves) on the river, basin or sea (Deltares, 2018). The probabilities are determined using statistical analysis of measured values or hydrological and hydraulic model calculations. For inner dike areas, the difference between exceedance probabilities and flood probabilities is important, but for unembanked areas, the flood probability is directly related to the exceedance probability (probability of reaching or exceeding certain value) of a water level (Deltares, 2018).

Types of risk
In the Dutch approach, typically three types of risk are considered for flood risk (Kok et al., 2017; Vergouwe, 2016):

- annual expected damage (or economic risk)
- individual risk
- societal risk

Economic risk is the economic valuation of probabilities of various possible damages, expressed in euros or euros per year. In cost-benefit analyses, the economic risk is frequently represented by the yearly anticipated value of damage, which results from multiplying the probability and damage (Kok et al., 2017). This figure can serve as an indicator of the economic risk value within CBAs, where investments in flood protection are balanced against the reduction in flood risk resulting from these investments (Vergouwe, 2016). Societal risk is a risk measure that provides insight into the probability of large numbers of victims. Understanding this is important because disasters in which large numbers of people die have a greater societal impact than much more frequent, smaller incidents (Kok et al., 2017; Vergouwe, 2016). The local individual risk (LIR) is a risk measure of the probability that an imaginary person permanently residing somewhere will die due to flooding, taking into account the possibility of evacuation. Setting a limit on the LIR creates a basic safety level for everyone in living within the dike-ring system in the Netherlands (Kok et al., 2017).

3.3. Multi-layer safety approach

For a long time, flood risk management in the Netherlands was dominated by a protection-oriented approach, largely relying on technical flood prevention measures like levees and dikes (De Moel et al., 2014). Nevertheless, in the last decades flood risk management has shifted to a more integrated risk management approach including measures that reduce damage and exposure (Van Buuren et al., 2016). In the Netherlands, this resulted in the introduction of the multi-layer safety (MLS) framework in 2009 (Rijkswaterstaat, 2009). This fits the notion of integrated flood risk management pushed by the European Floods Directive (2007/60/EC) which aims to '*reduce and manage risks that floods pose to human health, the environment, cultural heritage and economic activity*' (Bosoni et al., 2021).

In the National Waterplan 2009-2015 the Dutch government introduced the MLS concept, see Figure 12 (Rijkswaterstaat, 2009). The idea behind this is to lead to a more sustainable flood safety policy. It is suitable for elaborating an area-based risk approach that does not only look at water safety through flood defences, but on a broader scale by including spatial planning and crisis management (Van Der Most et al., 2017).

In the MLS-approach the three layers that are distinguished are (Rijkswaterstaat, 2009):

1. *Prevention:*
   aimed at reducing the probability of flooding by implementing a structural measure in an area (e.g. embankments and slopes, dikes and storm surge barriers)
2. *Damage reduction through spatial interventions:*
   design the area in such a way that the consequences of a flooding are mitigated (e.g. building codes, water proofing buildings and raising sites)
3. *Crisis management:*
   measures that limit the consequences in the event of a (threatened) flooding (e.g. evacuation plans, emergency measures such as sandbags or advanced emergency dikes)

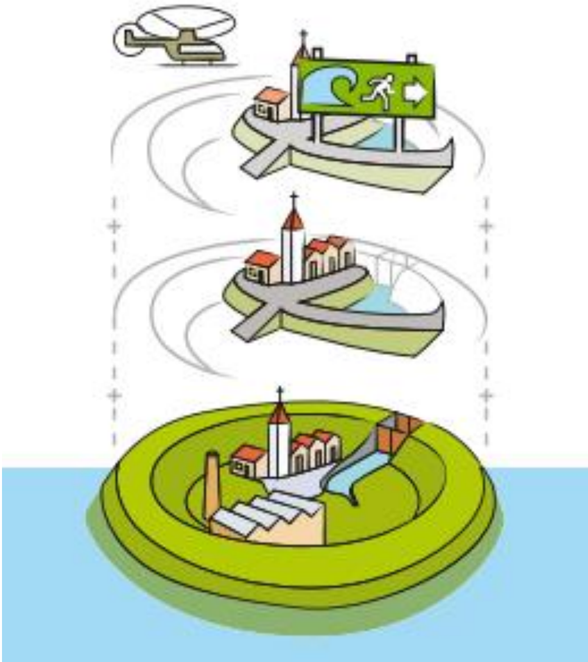


Figure 12: Multi-level safety approach: layer 1 (bottom, layer 2 (middle) and layer 3 (top) (Rijkswaterstaat, 2009)

The Delta Programme concluded in 2014 that prevention in Netherlands is the most important layer and that the other two layers are complementary. This conclusion was adopted by the government and parliament (Kok et al., 2017). Although the layers complement each other, organization of crisis management is needed anyway 'for when things do go wrong', but can sometimes be a deliberate choice as an independent solution, e.g. creating a second emergency-infrastructure (Rotterdams WeerWoord, 2021b).

Since a lot of attention is paid to layer 1, thus leaving a very small residual flood risk, it is often not profitable to invest in layer 2 within the embanked part of the Netherlands (De Moel et al., 2014; Urban Green-Blue Grids, n.d.). This is different for unembanked areas, as investments here are more rewarding and the motivation for these investments is greater among public and businesses (Urban Green-Blue Grids, n.d.). However, realising safety in layers 2 and 3 is complex since more parties are involved than in layer 1. Responsibilities for e.g. dike rings lie mostly with Rijkswaterstaat and water boards, while measures in layers 2 and 3 involve provinces, municipalities and private parties and thus requires more coordination (Potz et al., 2014). Also, costs for measures in layers 2 and 3 will fall on new parties, such as developers, local authorities, businesses and citizens (Potz et al., 2014). Oukes et al. (2022) did research on why the second layer measures are still limited used in practice and found an important institutional-organization barrier: '*a false, low or non-existent safety perception or risk awareness, and therefore a lack of urgency to act; a lack of political and societal support; a suboptimal collaboration between stakeholders; ambiguity regarding responsibilities; finances and a cost-benefit imbalance; and a lack of human capital.'*

Despite the fact that the MLS-approach in the National Water Plan 2009-2015 originally was designed for protection of embanked areas, studies shows that the layer classification is applicable in unembanked areas as well (De Moel et al., 2014; Gersonius et al., 2015; Nationaal Deltaprogramma Rijnmond-Drechtsteden, 2022; Potz et al., 2014; van Ledden & van de Visch, 2016). Moreover, since in the Pilot Water Safety Botlek (2016) it has been proven to be applicable, it is also used in the subsequent adaptation strategies for other port areas in Rotterdam. As these layers complement each other, the choice requires an integral consideration at the area level. Protection from flooding in unembanked areas requires a tailor-made approach and the choice of measures can depend heavily on the location and its character (Rotterdams WeerWoord, 2021b).

Finally, the severe flooding in province of Limburg, the Netherlands, in 2021, resulting in major material and emotional damage, has led the *Beleidstafel wateroverlast en hoogwater* to recommend expanding the MLS concept from three to five layers. Water awareness and recovery should be added. The policy table considers it very important that Dutch people are aware of flooding caused by extreme precipitation, for example. And it is important that unavoidable damage can be repaired and that damage is prevented from recurring (Harbers, 2022). Figure 13 shows the MLS approach with the two layers added.

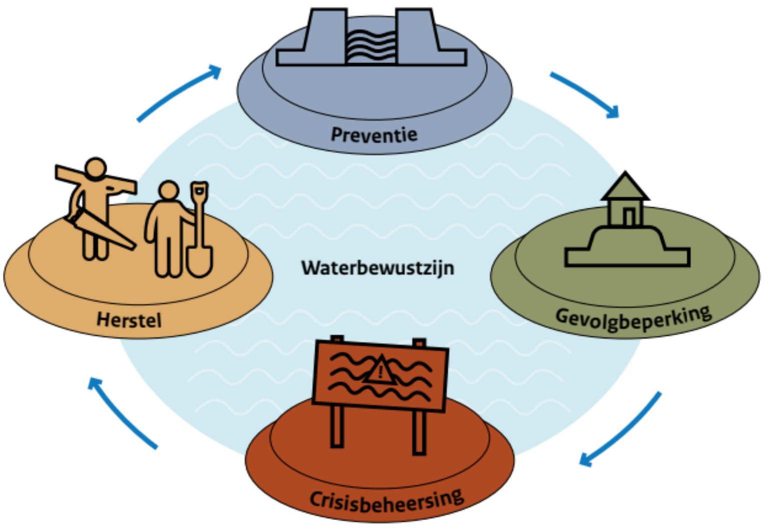


Figure 13: Proposed extended MLS-approach (Harbers, 2022)

3.4. Cost-benefit analysis

In the Netherlands, social cost-benefit analysis (CBA) has been a crucial instrument for managing flood risk and water governance for more than a century (Bos & Zwaneveld, 2017). But before delving into how CBA and other different evaluation methods have been used in previous research in flood risk management in unembanked areas, these evaluation methods will be explained in this and the subsequently section.

Starting with CBA, this tool serves as an objective means to evaluate policy alternatives or measures, quantifying their effects, uncertainties, costs, and benefits in monetary terms. This approach facilitates comparisons and empowers decision-makers to assess whether the benefits outweigh the costs (Romijn & Renes, 2013). By expressing diverse effects in monetary terms, CBAs enable the comparison of aspects such as nature, safety, cultural heritage, and social cohesion. This, in turn, contributes to the assessment of trade-offs and aids in the evaluation of policy decisions (Romijn & Renes, 2013). A comprehensive guide for conducting CBAs has been formulated by CPB and PBL in 2013 (*NL: Algemene Leidraad voor maatschappelijke kosten-batenanalyse*). This guide delves into the fundamental principles and background of CBAs, the process of drafting and preparing one, determining impacts, benefits, and costs, handling risks and uncertainties, and presenting outcomes (Romijn & Renes, 2013).

However, note that the term CBA is not used consistently in the literature, or, for example, are formulated differently in translation from Dutch to English or vice versa. An example of this is the just-mentioned CPB and PBL guideline, which in Dutch is called "*Algemene Leidraad voor Maatschappelijke Kosten-Baten Analyse*" and is translated into English as "*General Guidance for Cost-Benefit Analysis*" (Romijn & Renes, 2013a; Romijn & Renes, 2013b). Here you see that the word '*maatschappelijk*', meaning 'social' in English, does not emerge clearly in the translation. In addition, social cost-benefit analysis is abbreviated as CBA in one instance and as SCBA in another instance. Furthermore, the term CBA can be interpreted more broadly, considering the various intermediate forms. Hence, in literature, it is at times unclear whether a full CBA or another form is meant, as the terms are often intertwined.

Essentially, a CBA evaluates project or policy alternatives based on their implications for overall societal prosperity and well-being, weighing the social costs against the benefits. This involves systematically mapping all relevant effects of policy alternatives, quantifying and monetizing them whenever possible to enable aggregation and meaningful comparison. The analysis contrasts the effects of policy alternatives with the baseline scenario, representing the most likely development without new policies. The main drawbacks of a CBA include challenges in accurately valuing intangible factors, uncertainties in predicting future costs and benefits, potential biases in the decision-making process, and the complexity arising from the extensive information and time required for conducting a comprehensive analysis (Romijn & Renes, 2013).

To ensure a CBA is as useful as possible, the general guidance of Romijn & Renes (2013b) point out that the following must be taking in mind:

- *'Choose a suitable form for the CBA. This will depend on the stage of decision-making and the available knowledge about the main effects of the measure. Sometimes it will be possible and necessary to carry out a full CBA in which all aspects are worked out in detail. Sometimes a broader brush indices CBA will be adequate (or it may be the only feasible option).'*
- *'Consider doing a cost-effectiveness analysis (CEA) if all the measures to be investigated have the same (main) effect.'*

- *'If the main effects cannot be properly measured or monetised, use the principles of CBA as a conceptual framework. This will help to structure the decision-making, but will not result in a CBA and may not be called a CBA.'*

The general guidance of Romijn & Renes (2013b) describes the requirements to be met when determining effects and the (dis)advantages of various methods for doing this. Next to a few others, the most important rules for determining effects in a CBA are:

- *'The determination of effects should be based as far as possible on traceable, verifiable and falsifiable studies.'*
- *'A qualitative effect determination in which those involved or affected are asked to estimate the effects of the policy measures is not a suitable method for use in a CBA.'*
- *'A CBA based mainly on assumptions rather than empirically measured effects cannot be used in support of decision-making.'*
- *'If there are large differences in the degree to which different groups in society benefit from a measure or the distribution of costs and benefits is a major issue in the policy debate, the distributional effects must be considered in addition to the benefit/cost balance.'*

It is important to note that CBA does not assign value to the distributional effects on different societal groups, yet it can uncover and describe these effects, thus providing a comprehensive perspective on policy impacts (Romijn & Renes, 2013; Verdelingseffecten, n.d.). The report *Aanvulling op de Leidraad OEI 'Verdelingseffecten'* indicates that it is important to think carefully about the distributional effects to be mapped in preparation for the CBA (Ministerie van Verkeer en Waterstaat, 2004). Understanding the distributional effects can structure the funding discussion when multiple (government) parties are considering investing in a project. For example: Party A, B and C all want to contribute in financing a project. If the CBA shows the welfare effects for the three parties and it turns out that the project mainly benefits Party A and hardly benefits Party B, this can be taken into account in the funding discussion. If a project aims to benefit a particular group (or at least to ensure that a particular group is not disadvantaged), it is useful to understand the distributional effects for that group. It is necessary to assess which distributional effects are important to politicians (distribution between users and local residents, regions within the Netherlands, governments and private parties, etc.).

3.4.1. Different forms of CBA

A complete CBA may not always be essential, beneficial, or feasible at every stage of the decision-making process or for all categories of measures. To ensure broad applicability, the intricacy and depth of a CBA should be adjusted to meet the specific requirements of the decision-making process in question. Therefore, there are various intermediate forms of a CBA that impose less stringent requirements than a complete CBA. Even a CBA that does not quantify and monetize all effects can be useful for assessing project or policy alternatives. The advantage of these intermediate forms is their ease of application compared to full CBAs, while still incorporating the same systematic steps and economic theoretical background. This systematic approach ensures that only effects leading to changes in welfare are considered, preventing double counting. The downside of lighter CBAs is that their outcomes are accompanied by more uncertainty, thus providing less robust information.

Indicative CBA or Quick-scan (NL: Indicatieve KBA))

In an indicative CBA or quick scan, well-founded assumptions are made to provide an indication of the magnitude of effects in relation to costs. Only the most significant costs and benefits are quantified. If the objective of a particular policy can be valued in monetary terms, an indicative CBA, for instance, may offer insights into the justified investment for that objective. Another possibility is that an indicative CBA provides insights into the effectiveness required for a policy to result in a positive societal balance.

Key Figures CBA (NL: kengetallen KBA (kKBA))

A key figures-CBA operates following the principles of a CBA, but details about the effects and their magnitude are derived from universally applicable key figures obtained from other studies. In certain domains, such as the social sector, key figures are limited in availability.

Complete CBA (NL: Volledige MKBA)

In a complete or full CBA, all effects are expressed as much as possible in monetary terms. A complete CBA is usually based on research into alternatives, effects, and scenarios specifically conducted for that project or policy measure.

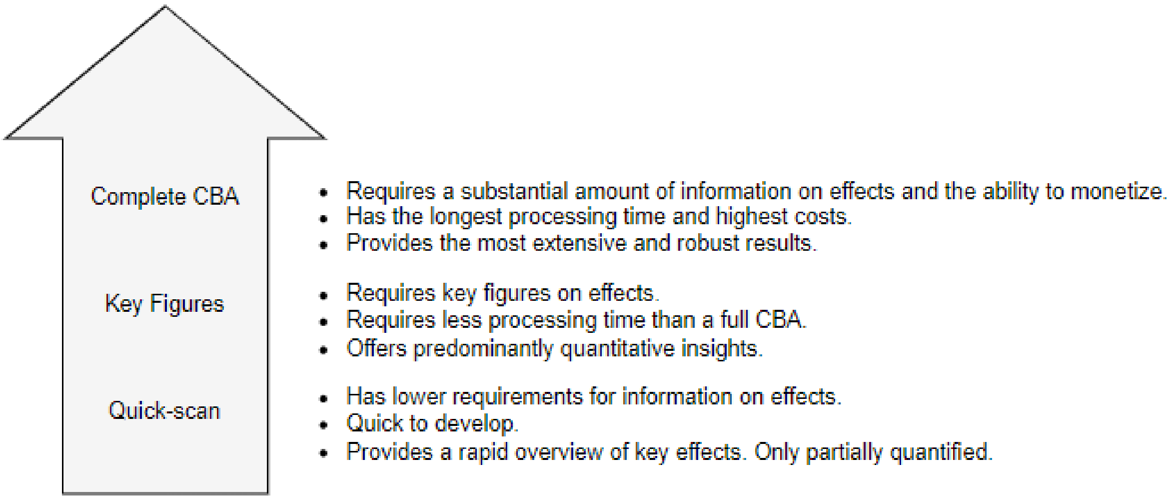


Figure 14: characterisation of the different variants of CBAs. Note: more intermediate forms exist (Translated from Faber & Mulders, 2012)

3.5. Relation to other evaluation methods

This study aims to achieve a better understanding of decision-making for flood risk measures in area development in unembanked areas. Besides CBA, there are more evaluation methods used to support decision-making for flood risk measures. It is crucial to clarify the definitions as they are used in the research and articulate the differences effectively. For robust decision-making, it is important to examine the role of various methods in the decision-making process, ultimately aiming to utilize the most suitable approach. As will be shown in this research, some evaluation methods have been widely used in theory and practice to support decision-making for flood risk measures in unembanked area development. In this part these methods will be explained in more detail. Please note that more alternative instruments or variants exist as well, but these are some of the most used. The information and explanations on the different methods are based on the reports of Faber & Mulders (2012) and Romijn & Renes (2013b). Table 3 gives an overview of the different evaluation methods including the advantages and its limitations.

Cost-effectiveness analysis (CEA)

A special form of CBA is the cost-effectiveness analysis (CEA). A CEA assesses the costs needed to achieve specific (societal) effects (cost minimization) or which policy alternative, given a certain budget, maximally contributes to the objective (effect maximization). Unlike in a CBA, the effects in a CEA are not monetized. In its pure form, a CEA does not consider side effects (such as distribution effects, environmental effects, etc.). If there are side effects or if the effects in different variants are dissimilar, the outcome of the CEA can be challenging to interpret because the effects are not expressed in the same unit. A CEA can thus be seen as a CBA with a given, fixed objective scope. However, the way a CEA is set up does not differ significantly from a CBA. The research techniques and principles are also similar. There is a grey area between CEA and CBA, as a CBA with alternatives that all (including the zero-alternative) achieve a narrowly defined goal is essentially a CEA.

Multi-criteria analysis (MCA)

In a MCA, all effects are being considered, just like in a CBA, with a crucial distinction being that MCA does not express effects in monetary terms but assigns a weight to each effect. The risk of double-counting effects and the risk of poorly substantiated weight choices are greater in MCA than in CBA. In MCA, politicians and/or policymakers determine the weights of various policy effects, making this method subjective and potentially manipulable since changing the weights will influence the outcome. The primary advantage of MCA is its ability to incorporate effects that cannot be monetized. Additionally, the involvement of policymakers in the research is sometimes seen as a positive aspect. However, CBA is better suited than MCA to serve as an independent policy assessment.

It is sometimes argued that the best approach is a mix of a CBA for monetizable effects and an MCA for the other effects (Sijtsma, 2006; Duivesteijn et al, 2011). Sijtsma (2006) combines MCA and CBA within a sustainability context into an evaluation tool called ‘MCCBA’. In this method, only the impacts that are considered well-suited for monetary measurement in CBA by various stakeholder groups should be included. To distinguish MCCBA from traditional CBA, the term 'limited CBA' is employed in the MCCBA approach, emphasizing its narrower focus.

Impact assessment (IA)

Impact Assessment (IA), which is known under many names such as Scorecard Analysis, Performance Matrix and Key Performance Indicators, solely illustrates the effects without weighing them against each other or making them otherwise comparable. An example of such an impact assessment can be seen in Figure 18 in the following subchapter. The advantage of this method is the absence of a (potentially subjective) weighting process. However, the drawback is that the effects are not made comparable or additive, often resulting in a lack of clarity about which policy options emerge as the best solution. As more and more important effects cannot be monetized, a CBA increasingly resembles an IA.

Table 3: Summary of evaluation methods incl. advantages and its limitations

Method	Explanation	Advantages	Limitations
Cost-benefit analysis	Systematically assesses all costs and benefits of a project or policy, incorporating societal impacts	- **Monetary Evaluation:** CBA expresses all effects in monetary terms, facilitating comparability and aggregability of costs and benefits. **- Comprehensive Assessment:** CBA evaluates a wide range of effects, including social, economic, and environmental impacts, providing a holistic understanding. **- Transparency and objectivity:** CBA requires a systematic and transparent approach, enhancing decision-making and accountability - **High-quality information**: Unlike MCA, CBA is vigilant about double counting and is qualitatively superior to other methods because costs and benefits evolve over time and are discounted to its present value. - **Distributional effects**: Ability to map welfare effects for different stakeholder groups.	- **Lack of Completeness:** It's challenging to comprehensively capture all costs and benefits. Some may be difficult to quantify, and non-financial aspects like environmental impact, social effects, and ethical considerations might be overlooked - **Uncertainty**: Future events are uncertain, and CBAs are sensitive to changes in assumptions. Outcomes of a CBA can vary significantly based on these assumptions, reducing reliability. - **Time and Resource-Intensive**: Conducting a thorough CBA can be time and resource-intensive, especially for large-scale projects. This can result in decision-making delays. - **Potential Political Influence**: CBA outcomes can be influenced by political pressure or stakeholder interests, jeopardizing objectivity.
Cost-effectiveness analysis	Assesses the efficiency of different interventions or policies by comparing their costs in relation to the achieved outcomes	- **Targeted and clear:** CEA focuses specifically on one non-monetized effect, making the policy objective clear and keeping the research straightforward. - **Easy application:** Compared to MCA and CBA, CEA is simpler to apply because it assesses costs in relation to one specific effect, without the complexity of monetizing diverse effects. - **Limited subjectivity:** Since CEA focuses on one effect, it limits subjectivity in assigning weights to different effects, which is often the case in MCA. **- Specific focus on effectiveness:** CEA emphasizes cost-effectiveness, making it a suitable method to determine which policy option is most effective given a fixed budget. **- Clear interpretation:** The outcomes of CEA are often more easily interpretable because effects are not expressed in different units as in MCA, and it avoids the complexity of fully monetizing effects as in CBA.	- **Limited scope of evaluation:** CEA tends to focus solely on a specific, outcome without considering broader impacts, making it less comprehensive than MCA and CBA. **- Exclusively economic focus:** CEA's exclusive emphasis on economic considerations may result in overlooking social or environmental factors, a drawback compared to comprehensive assessments like MCA and forms of Impact Assessment. **- Difficulty in comparing diverse effects:** CEA may struggle when comparing disparate effects that cannot be easily measured in the same unit, a challenge addressed more effectively by MCA and certain IA methodologies. - **Risk of oversimplification:** In aiming for economic efficiency, CEA might oversimplify complex scenarios, missing nuances and potential unintended consequences, a risk that more intricate methods like MCA and certain IA's seek to mitigate.
Multi-criteria analysis	Systematically evaluates and compares various alternatives based on multiple criteria, considering diverse factors (qualitative and quantitative)	**- Comprehensive Evaluation:** MCA considers multiple criteria, accommodating qualitative and quantitative factors, providing a holistic assessment. - **Inclusivity:** MCA allows for the incorporation of diverse stakeholder perspectives, fostering a more inclusive decision-making process. - **Flexibility of non-monetizable effects:** MCA is adaptable to situations where certain impacts cannot be easily monetized,	**- Subjectivity:** MCA involves subjective judgments in assigning weights to criteria, potentially introducing bias into the decision-making process. - **Quantification Challenges:** Assigning precise values to qualitative criteria can be difficult, leading to challenges in quantitative comparisons. **- Trade-off Difficulties:** Balancing conflicting criteria can be challenging, and the process of making trade-offs may lack a clear, universally accepted methodology.

		offering flexibility in considering various types of criteria. **- Robustness:** MCA is robust in handling uncertainties and complexities, making it suitable for scenarios with incomplete or uncertain information.	- **Double-counting:** reduces the accuracy of the evaluation by overlapping influences of criteria, thereby compromising the reliability of the results
Impact assessment	Systematic process to evaluate and measure the effects and outcomes of a project, policy, or initiative on various criteria to inform decision-making.	- **Broader Evaluation:** Impact assessments focus on a wider range of criteria, both financial and non-financial, providing a more comprehensive view of the consequences of a project. - **Qualitative Aspects:** They can assess non-financial aspects and qualitative effects, including social, ecological, and cultural factors. **- Stakeholder Engagement:** Impact assessments often promote stakeholder engagement, leading to more inclusive decision-making. - **Contextual Relevance:** They may be better tailored to the specific context and objectives of a project.	- **Subjectivity:** Because they rely on qualitative evaluations, impact assessments may be subject to subjectivity and interpretation differences. - **Time-Consuming:** Conducting a thorough impact assessment can be time-consuming and may slow down decision-making. - **Limited Uniformity:** There may be a lack of uniformity in methodologies and approaches for impact assessments, complicating comparisons.

3.6. CBA in flood risk management

Bos and Zwaneveld (2017) made an overview of many examples for CBAs in flood risk management and water governance in the Netherlands such as the CBA in the 1901 Zuiderzee Act, Van Dantzig's famous formula for the economically optimal strength of dikes and a whole series of CBAs for 'More Room for the Rivers' and the Delta Programme. Since the 1953 flood disaster in the Netherlands, it became clear that a more comprehensive method was needed to determine safety levels for prevention measures (Lendering, 2018). In 1956 van Dantzig developed a risk-based approach to derive and assign safety standards to flood defence systems (Van Dantzig, 1956). Safety standards were derived by optimising the costs of raising flood defences against the benefits.

In recent decades, the results of CBAs, primarily using the van Dantzig method, have been employed to provide support for the revision of flood protection standards. This involves investing in the flood defence just until the costs of the last investment barely outweigh further reduction in expected damage. At that point, the total costs are minimal and, the level of protection is optimal (Deltares, 2011). Furthermore, the current used issue levels of Rotterdams policy for new developments in unembanked areas is based on van Dantzig’s principle (Mooyaart & Schoemaker, 2017). Figure 15 graphically shows how the principle works based on the study for determining the current used issue level in Rotterdam.

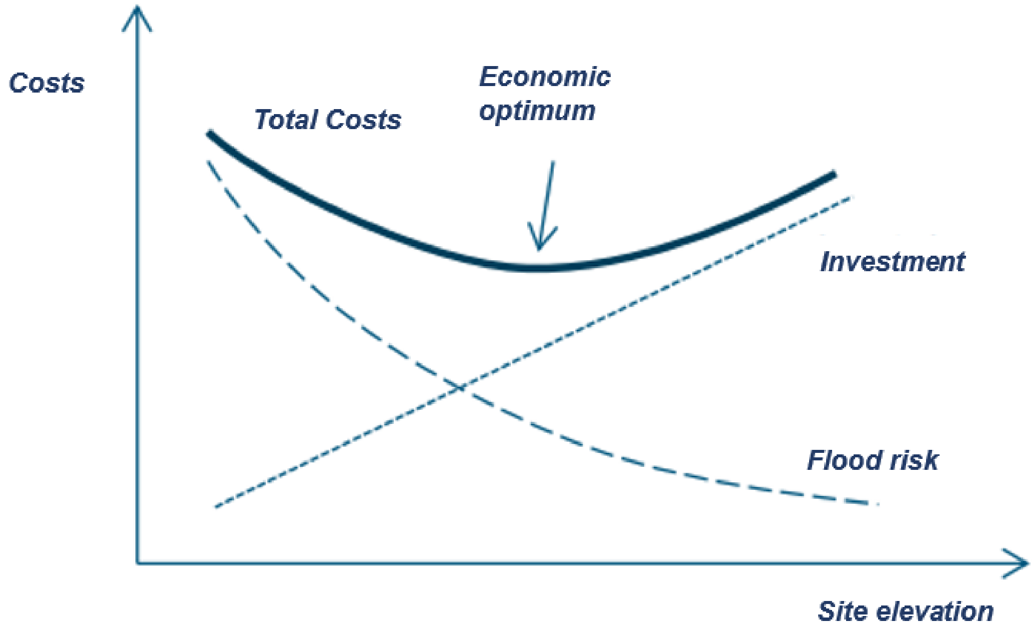


Figure 15: Economic optimum according to the Van Dantzig principle (Translated from Mooyaart & Schoemaker, 2017)

The overview of CBAs created by Bos and Zwaneveld (2017) only deals with large-scale projects and does not mention or give examples of local developments in unembanked areas. Deltares was commissioned by the Ministry of Infrastructure and the Environment to carry out a CBA and analysis of loss-to-life risk for the substantiation of water safety standards of dike rings (Deltares, 2011). As well Kind (2014) uses a cost-benefit analysis and adds a Monte Carlo analysis to find the economically efficient flood protection standards of dikes. These studies demonstrate that, despite substantial study on CBA in flood risk management, the protection of unembanked areas have not been a primary focus.

In addition, Lendering et al. (2018) argue that in order to evaluate the effectiveness of flood adaption innovations, risk-informed decision-making must be based on factors like costs and benefits over the lifetime of the innovation, where benefits are expressed as damages avoided (i.e., annual risk reduction). In their paper, CBA was employed to compare the cost-effectiveness of emergency measures with dike reinforcements for flood risk reduction, revealing that permanent reinforcements are more cost-effective for high initial failure probabilities (Lendering et al., 2018).

3.6.1. Dealing with non-monetary effects

The anticipated interventions to manage present and future flood risks are likely to significantly influence the spatial quality and potential of regions, emphasizing the need for an integrated approach that combines flood risk and spatial quality considerations (Nilessen, 2019). Decisions on flood alleviation measures that are solely based on avoidance of material damage may be too limited, as the social impact of a flood is not considered within this decision-making (Coninx & Bachus, 2007). In addition, Werritty et al. (2007) findings show that CBA for flood alleviation schemes should take intangible social aspects into account, as it showed that intangible impacts (related to non-material effects e.g. stress or fear of flood and/or emotional losses) registered significantly higher values than tangible impacts (related to material losses). Moreover, Bos and Zwaneveld (2017) do show the importance of considering non-monetary effects in flood risk management like quality of landscape (spatial beauty), quality of environment, social consequences and flexible water management.

Furthermore, Bos and Verrips (2019) as well state that it is important to consider non-monetary benefits of area development, such as impacts on nature, landscape and historical heritage, and present them in a balanced way in an overview table and summary of a CBA, if these benefits are important in a quantitative or qualitative sense. During the exploration of an CBA-tool for climate-adaptive measures, incorporating all relevant impacts into a monetary framework is challenging, often due to difficulties in quantifying and monetising certain impacts like the effects on spatial quality (De Blaeij et al., 2019; Nilessen, 2019). This is confirmed by research of Mouter (2014) who did research on CBAs in practice. From respondents in his research the most given reason is that is difficult to monetize effects on landscape and open space, effects on housing, effects on urban quality, cultural heritage, aesthetic quality, was because of the lack of an adequate valuation methods (Mouter, 2014).

Joseph et al. (2014) present a conceptual cost-benefit analysis framework for property level flood risk adaptation (PLFRA) measures that include intangible benefits like reduction of stress and depression, as they as well see the limitations of non-inclusion of intangible effects in previous studies. In their literature review on existing CBA models on PLFRA measures, they found that non-inclusion of intangible benefits such as reduced anxiety and improved social cohesion, could make the application of CBA on household levels less robust. They concluded that based on that '*the most important benefits of flood risk adaptation at household levels are the intangible benefits (Green and Penning-Rowsell, 1989; Environment Agency and DEFRA, 2004; Joseph et al., 2011) and the inclusion of the intangible benefits has the potential to provide more robust decision-making information for homeowners and flood risk management stakeholders'* (Joseph et al., 2014).

Doeffinger and Rubinyi (2023) reviewed if secondary benefits are included and quantified in CBAs for flood protection and argue that a thorough understanding of secondary benefits of urban flood protection, could unlock additional financing for flood protection infrastructure. Pesaro et al. (2018) investigated CBA for non-structural flood risk mitigation measures. They argue as well that investment in flood risk management might produce a system of other positive externalities which should be better taken into consideration in decision-making processes about the selection of the flood risk measure and neglected negative externalities resulting from flood mitigation interventions, particularly structural ones, should be factored into the analysis as they could influence the attractiveness of alternative measures at the system level (Pesaro et al., 2018).

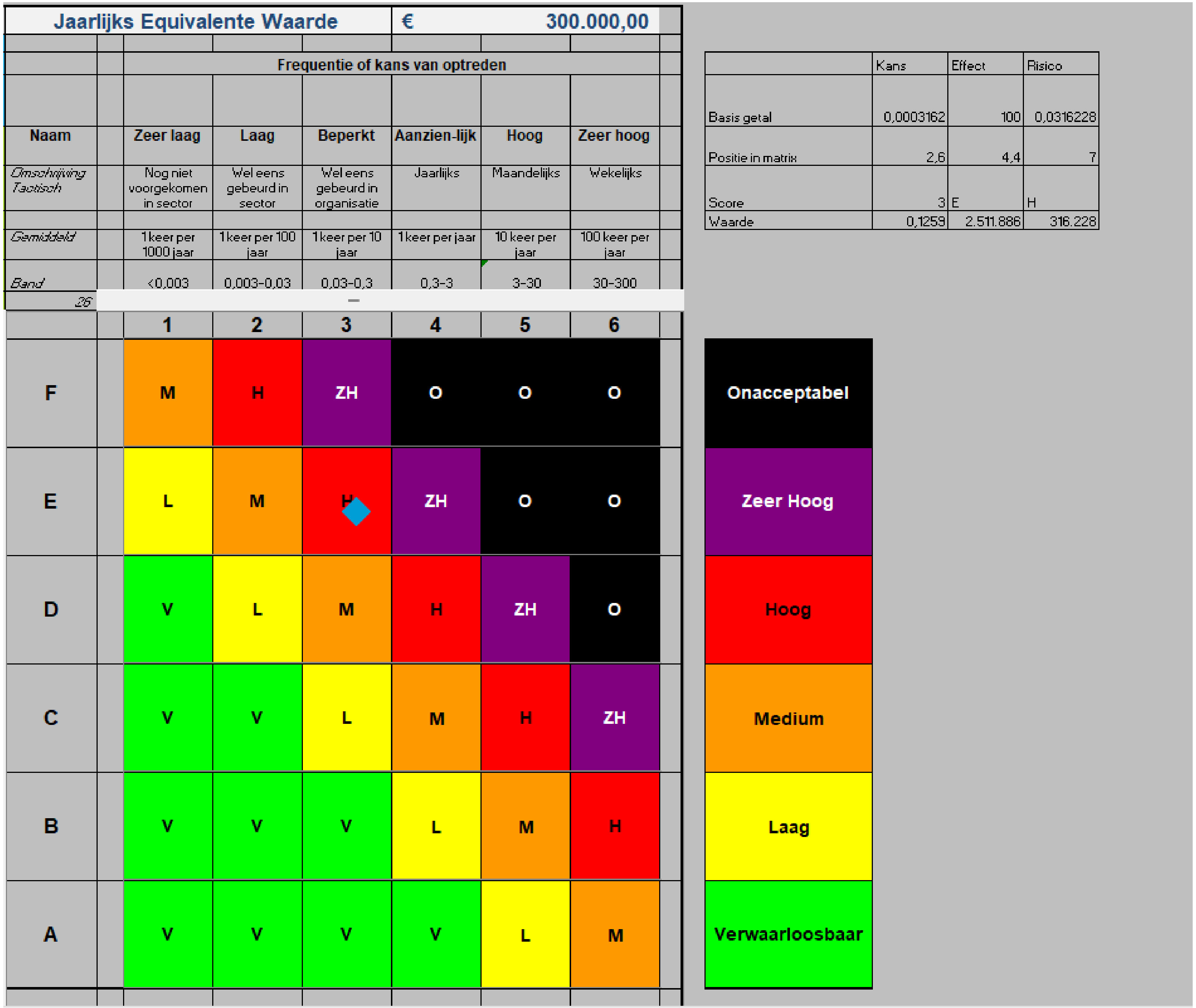
Booister, Hekman, et al. (2021) show that the benefit-cost ratio (BCR) for climate-adaptive construction in urban areas is positive and that the economic efficiency of climate measures increases as the measures also contribute (temporarily or permanently) to other values. A relatively new concept, the triple dividend of resilience (TDR), highlights these additional different types of benefits in disaster risk management. The approach considers 1). avoided losses, 2). induced economic or development gains and 3). additional social and environmental benefits of adaptation actions (Heubaum et al., 2022). As they say that *'accounting for the full range of benefits demonstrates higher BCRs for adaptation investments than are often assumed. In turn, this can help increase access to project finance, improve project design, and improve ex post monitoring and evaluation'* (Heubaum et al., 2022).

While expressing societal values in monetary terms remains challenging, efforts are ongoing to develop frameworks to still make this possible. For instance, the municipality of Rotterdam has designed a societal values model for asset management. Inspired by the 6-capitals model of the International Integrated Reporting Council (IIRC), this tool aims to quantify societal values for conducting tactical risk assessments of public assets, as depicted in Figures 16 and 17. Please note that this version is still conceptual; it is presented here solely as an indication that work is being done on such frameworks.

Waarrden	Financieel	Materieel		Intellectueel		Mens		Sociaal		Natuur	
	Betaalbaarheid	Bruikbaarheid	Kwaliteit	Dataveiligheid		Veiligheid	Gezondheid & welzijn	Betrouwbaarheid		Biodiversiteit	Duurzaamheid & Milieu-vriendelijkheid
Indicator	Waardeverlies: I schade/ onverwachte/ ongeplande uitgave	# verloren volle gebruiksdagen Fundamentele (f), primaire (p), secundaire (s) en tertiare (t) assets (partiële beperkingen tellen fractioneel).	Conditieverlies: volume (#/m2) * ernst van aantasting (a-d, 1-6) * belang van het object (standaard, landmark, monument). Meting in conditieverlies punten. Zwervuil is onderdeel van conditieverlies	Verlies en verminking data	Security inbreuk	Fysieke veiligheid (# slachtoffers met ernst letsel in letselpunten (lpt))	Ziekteverzuim, verlies levensduur, ontevredenheid, overlast (allen in dagen)	Compliance (# rechtszaken, boetes, schikkingen gewogen naar ernst)	Reputatie (# rumoer gewogen naar ernst)	Aangetast oppervlak in m2: Ernstig (onherstelbaar), Matig aangetast (regeneratie 0,3-3 jaar), Licht (regeneratie <0,3 jr), kg dode biomassa	vervuiling Lucht: ton CO2 eq (NOX/HC/CO 200 eq, fijnstof 20.000 eq) Water: m3 DWE; Land: kg zwerfvuil
Eenheid	I	pt	Cvp			lpt	pt	pt	pt	pt	pt
Bovengrens	10.000.000	10.000	2.000.000			10.000	10.000	10.000	10.000	10.000	10.000
Ernstcategorie											
Extreem	>10 M	>10k GDf >100k GDp >1M GDs >10M GDt	>2M cvp > 200 ha vervuild	Volledig archief op straat (wikileaks)	Onherstelbare schade (stuxnet)	Meerdere doden	>20k VZD >40k LVD >1M OTD >10M OLD	Stille curator, Strafrechtelijke veroordeling bestuurder,	Internationale commotie/ langdurig geen bestuur	>10 ha E >100 ha M >1000 ha L >100 ton bio	>200 kton CO2 eq > 1M m3 DWE >400 ton vuil
Ernstig	1M-10M	1k-10k GDf 10k-100k GDp 100k-1M GDs 1M-10M GDt	200k-2M cvp 20-200 ha vervuild	Bundel zeer geheime stukken op straat	Herstelbare schade syteem (ransomware)	Een dode, blijvend ernstig letsel, invaliditeit	2k-20k VZD 4k-40k LVD 100k-1M OTD 1M-10M OLD	Strafzaak bestuurder	Landelijke commotie; motie wantrouwen/ opstappen gehele bestuur	1-10 ha E 10-100 ha M 100-1000 ha L 10-100 ton Bio	20-200 kton CO2 eq 0,1-1 M m3 DWE 40-400 ton vuil
Behoorlijk	100k-1000k	100-1k GDf 1k-10k GDp 10k-100k GDs 100k-1M GDt	20k-200k cvp 2-20 ha vervuild	Zeer geheim stuk op straat	Toegang tot root (admin rechten in systeem), Identity theft user	Ernstig gewonde, langdurig verlet, chronische ziekte	200-2000 VZD 400-4000 LVD 10k-100k OTD 100k-1M OLD	Dwangbevel, boete 6e categorie	Regionale commotie; motie van wantrouwen/ opstappen enkele bestuurder	1000m2-1ha E 1-10 ha M 10-100 ha L 1-10 ton Bio	2-20 kton CO2 eq 10-100 k m3 DWE 4-40 ton vuil
Matig	10k-100k	10-100 GDf 100-1k GDp 1k-10k GDs 10k-100k GDt	2k-20k cvp 0,2-2 ha vervuild	Geheim stuk op straat	Toegang alle rechten user, gebruik edit account	Ongeval met verlet ("Lost time incident"), beroepsziekte (RSI, Burn Out)	20-200 VZD 40-400 LVD 1000-10000 OTD 10k-100k OLD	Aanwijzing, boete 5e categorie	Lokale commotie , vragen en moties in volksvertegen-woordiging	100-1000 m2 E 0,1-1 ha M 1-10 ha L 0,1-10 ton Bio	0,2-2 kton CO2 eq 1-10 k m3 DWE 0,4-4 ton vuil
Klein	1000-10k	1-10 GDf 10 - 100 GDp 100-1000 GDs 1k-10k GDt	200-2k cvp 200-2000m2 vervuild	Vertrouwelijk stuk op straat	Toegang tot edit account, gebruik kijk account (download data)	EHBO / bijna ongeval	2-20 VZD 4-40 LVD 100-1000 OTD 1000-10000 OLD	Waarschuwing/ onderzoek bevoegd gezag, boete 3e categorie	>10 klachten / interne commotie	10-100 m2 E 100-1000 m2 M 0,1-1 ha L 10-100 kg Bio	20-200 ton CO2 eq 0,1-1 k m3 DWE 40-400 kg vuil
Minimaal	<1000	<1 GDf <10 GDp <100 GDs <1000 GDt	<200 cvp <200 m2 vervuild	Stuk voor beperkte verspreiding op straat	Toegang tot kijk account	Gevaarlijke situatie	<2 VZD <4 LVD <100 OTD <1000 OLD	Boete 1e categorie	< 10 externe klachten	<10m2 E <100 m2 M < 1000 m2 L < 10 kg Bio	<20 ton CO2 eq < 100 m3 DWE <40 kg vuil

44

Figure 16: Part 1 of table social values Rotterdam for tactical risk assessment public assets (Rotterdam & Asset Resolutions, 2023)



Jaarlijks Equivalente Waarde	€ 300.000,00					
	Frequentie of kans van optreden					
Naam	Zeer laag	Laag	Beperkt	Aanzien-lijk	Hoog	Zeer hoog
Omschrijving Tactisch	Nog niet voorgekomen in sector	Wel eens gebeurd in sector	Wel eens gebeurd in organisatie	Jaarlijks	Maandelijks	Wekelijks
Gemiddeld	1 keer per 1000 jaar	1 keer per 100 jaar	1 keer per 10 jaar	1 keer per jaar	10 keer per jaar	100 keer per jaar
Band	<0,003	0,003-0,03	0,03-0,3	0,3-3	3-30	30-300
26						
	1	2	3	4	5	6
F	M	H	ZH	O	O	O
E	L	M	H	ZH	O	O
D	V	L	M	H	ZH	O
C	V	V	L	M	H	ZH
B	V	V	V	L	M	H
A	V	V	V	V	L	M

	Kans	Effect	Risico
Basis getal	0,0003162	100	0,0316228
Positie in matrix	2,6	4,4	7
Score	3	E	H
Waarde	0,1259	2.511.886	316.228

Onacceptabel
Zeer Hoog
Hoog
Medium
Laag
Verwaarloosbaar

Figure 17: Part 2 of table social values Rotterdam for tactical risk assessment public assets (Rotterdam & Asset Resolutions, 2023)

As evident, efforts persist in attempting to quantify societal values in monetary terms. Additionally, there are frameworks that concentrate on qualitative criteria. Nilessen (2019) made a spatial quality assessment tool which is based on the *Ruimtelijke Kwaliteits Toets* (RKT) that had been developed and used as part of the Dutch ‘Room for the River’ (*NL:* ‘*Ruimte voor de Rivier’)* programme in 2006. The methodology was modified to assess the impact of extensive water-safety interventions on spatial quality at a local level within an urban delta region. Frequently mentioned criteria considered relevant for the Rijnmond–Drechtsteden area encompass having a direct 'view' connection to water, the potential for establishing new water-based living environments, the rationale behind an intervention, and the proportion of an intervention concerning the scale of the surroundings. Subsequently, the proposed methodology was used to analyse the impact of the four regional water-safety strategies defined for the Rijnmond-Drechtsteden region. Unlike current methods that demand specific design details for assessment, this approach enables the evaluation of large-scale water-safety interventions at earlier stages of development. Again, Figure 18 is just shown as indication of what an impact assessment could look like.

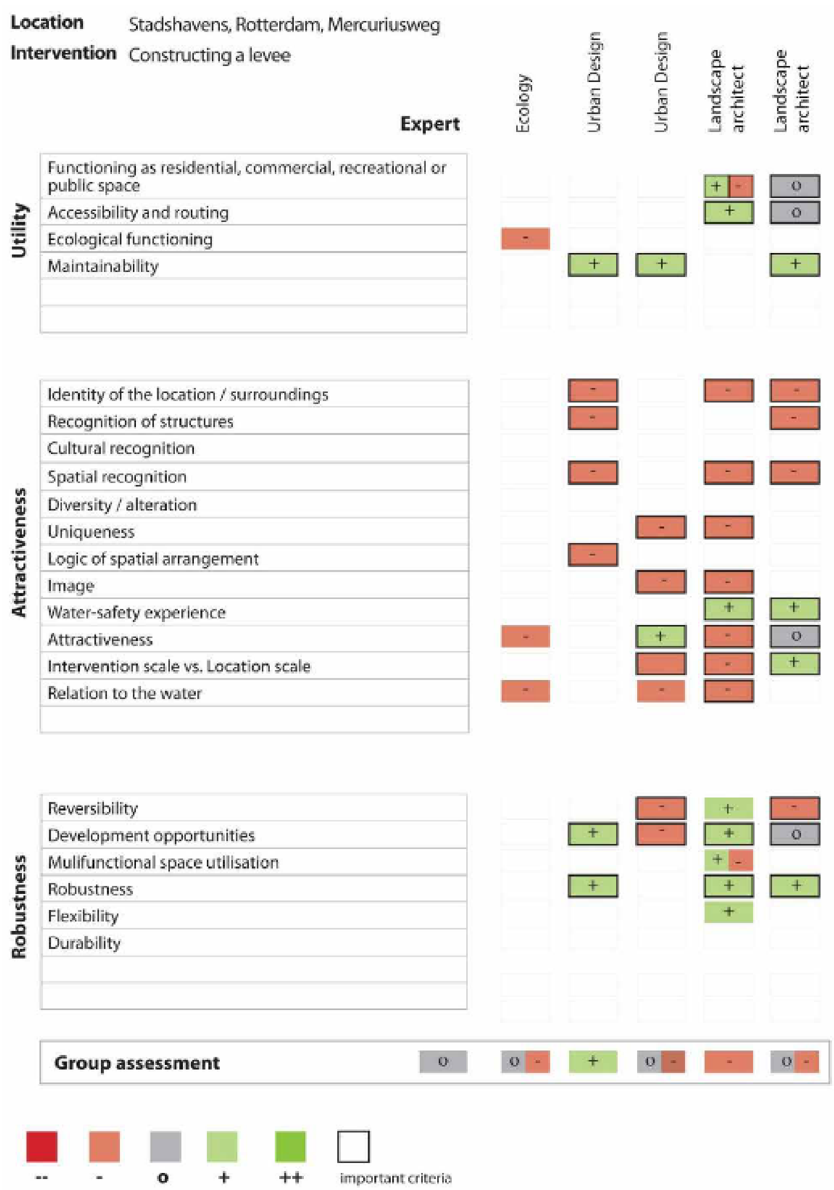


Figure 18: Assessment of the impact of constructing a levee as water-safety intervention in the unembanked redevelopment area (Nilessen, 2019)

3.7. Studies on unembanked areas

This sub-chapter will elaborate on studies specifically focusing on measures in unembanked areas and in the end, Table 4 will give an overview the different studies and the evaluation methods specially on adaptation measures in unembanked areas.

The paper of De Moel et al. (2014) is by far the most cited scientific paper on unembanked areas, cited 91 and 131 times according to Scopus and Google Scholar respectively. They present a methodology to evaluate measures in unembanked areas of Rotterdam by focusing on the second layer of the MLS framework, such as dry proofing, wet proofing or elevating buildings. The damage-reducing measures are implemented in their model, which uses the input of land-use and inundation depths, to eventually calculate the reduction in expected annual damage. A full cost-benefit analysis is however outside the scope of their research. Also, they say that '*ideally, cost-benefit analyses should be performed spatially, to allow for a distinction of where a measure may be most cost-effective'* (De Moel et al., 2014). On the contrary, De Ruig et al. (2020) performed a micro-scale CBA on building-level adaptation measures to sea level rise. They advise to either perform CBAs on areas that have been divided based on inundation depth, or conduction economic evaluations of building-level adaptation measures at the smallest scale possible.

Pohl et al. (2014) conducted research on the social cost-benefit analysis for a climate adaptation strategy in the Kop van Feijenoord. They utilized a different baseline alternative and variants than would be used nowadays, as the issue level policy of Rotterdam was not in place at the time, and this would now serve as the current baseline alternative. Their study provides a quantitative explanation of the key figures used and the effects of different measures. As far as my knowledge extends, Pohl et al. (2014) are the first and only researchers to explicitly address in a CBA which costs and benefits are borne by different actors for measures in an unembanked area. However, they do not offer a quantitative or qualitative demonstration of how the costs and benefits of the various potential variants are allocated among stakeholders, but only provide a general table illustrating which actor bears which costs and/or benefits.

Furthermore, in their CBA, the benefits are confined to water safety, neglecting other potential effects, whether positive or negative. Hence, their analysis could be regarded as a partial CBA, focusing selectively on one effect. Nevertheless, as they say themselves, consideration of other effects could significantly impact the results and Pohl et al. (2014) indicate that in further development of adaptation strategies, it is advisable to consider optimization concerning (side) effects. For instance, Pohl et al. (2014) highlight that the elevation of new or existing buildings may result in height disparities in the landscape, influencing landscape quality and liveability.

As well De Moel et al. (2014) recognize that factors beyond solely (cost) effectiveness of measures would come into play in decision-making for flood risk measures in unembanked areas, given that '*allowing areas to be flooded once in a while can have additional benefits like maintaining view on the river, preserving the atmosphere of historical area and creating new living environments'*. In addition, the report by Van Vliet et al. (2012) on the results of a workshop on multi-level safety in the unembanked areas of the Rotterdam-Drechtsteden region highlights the participants' emphasis during the concluding discussion, in which they underscored that in all calculations, it should not be forgotten that when searching for suitable measures, immediate focus on financial consequences is not always necessary. After all, there are several other important factors that are not easily quantifiable and common sense and sufficient attention to social safety, sustainability, biodiversity, and water experience should not be overlooked in the cost-benefit comparison (Van Vliet et al., 2012).

Adaptation strategies

Although CBA has been widely accepted as effective decision-making tool, incorporating climate change uncertainty into CBA of flood risk management strategies has been difficult (Van Der Pol et al., 2017). Recently, in the field of flood risk management, there have been developments in planning methods that prioritize resilience, enabling adaptative responses to changing circumstances. Two notable approaches, namely the adaptation tipping point (ATP) method and the adaptive pathways (AP) method, initiate the development of adaptation options by identifying critical vulnerabilities within the system. These methods aim to create a flexible portfolio of strategies to enhance overall resilience. Decision-makers in flood risk management focused on climate adaptation are facing fundamental uncertainties for which these methods prove to be an effective way to keep the decision processes going forward (Bloemen et al., 2017). Therefore, these approaches are mentioned to better understand the challenges in the decision-making process of adaptation measures.

The AP method offers a means to navigate uncertainty by using a sequence of water management policies or measures, known as an adaptation pathway, to guide decision-makers in selecting future adaptation options aligned with evolving environmental and societal conditions (Van Veelen, 2016). The ATP method serves as a valuable framework for assessing current policies and comparing new options, identifying the juncture at which climate change impacts necessitate a shift in approach to attain policy objectives. The AP and ATP methods play an important role in policy making in flood risk management and more specific research has been done on adaptation pathways for unembanked areas. For the unembanked areas in Rotterdam, it was concluded that the AP approach is an effective method to evaluate and select appropriate adaptation measures (Van Veelen et al., 2015). Moreover, using multi-criteria analysis or cost-benefit analysis methods, decision-makers can evaluate adaptation pathways in relation to various time horizons and situations (Haasnoot et al., 2013). CBAs has been widely applied to assess flood risk management strategies (Van Der Pol et al., 2017).

In the process of developing adaptive strategies, several steps are involved. Following a vulnerability assessment and the definition of adaptation thresholds, the next step, according to Van Veelen's (2016) research, involves exploring adaptation measures. After selecting possible measures (preventive, adaptive or recovery-based), Van Veelen (2016) says to '*evaluate adaptation measures on performance criteria (flood reduction, cost-effectiveness, social equity, spatial quality, additional benefits, negative side effects on other levels of the system)'.* Subsequently, the measures are combined into pathways and eventually these pathways are assessed with help of a MCA that employs criteria such as (cost-)effectiveness, potential benefits and other relevant criteria to weigh the different measures and combinations of measures (Van Veelen, 2016).

Moreover, in earlier research, one of his recommendations concerns the major challenge for involved parties for which 1) '*an agreement on the mutually accepted division of costs and benefits in the short and long term must be reached'* and 2) '*a workable arrangements to secure responsibilities, management of risk, and long-term investments will have to be develop"* (Van Veelen, 2013). Follow-up research by Van Buuren et al. (2015) take these two issues as a starting point for a co-creative research process to find out how the designed strategies could be made implementable and investigate the necessary governance arrangements. After working together with several stakeholders during their action-oriented research it could be concluded that for implementation it is difficult to work with different policy objectives on social disruption, damages and individual risk and that support from (local) stakeholders for measures in the adaptation strategies is utmost important (Van Buuren et al., 2015).

The approach of adaptive delta management (ADM) is consistent with the theory of adaptive pathways and this way of thinking is increasingly being applied in flood water management (Deltaprogramma, 2013). ADM takes large uncertainties into account in making investments decisions and links short-term decisions with long-term tasking, incorporates flexibility in possible solution strategies (adaptive pathways) and links different investment agendas (Deltapromma, 2013; Van De Brugge & Bruggeman, n.d.)). A paper of Gersonius et al. (2015) shows how ADM for flood risk and resilience can be used in the unembanked areas of the city of Dordrecht, the Netherlands. On of the major limitation they address within ATP approach, one of the key elements of ADM, is that due to the absence of legally enforced safety standards in the case of unembanked lands makes it difficult to define threshold values (Gersonius et al., 2015). In the Delta Programme for the next century, the governance approach of 'Room for water' and 'More room for rivers' was expanded with an ADM philosophy (Van Alphen, 2015). Throughout the various decision-making stages, CBAs were used to calculate the effectiveness, robustness and flexibility of diverse national and local adaptation strategies (Bos & Zwaneveld, 2017).

As already mentioned in the background information, for the city of Rotterdam several adaptation strategies have been constructed by Royal HaskoningDHV. The studies use roughly the same methodology, but there are some differences in approach per area. In all studies, first the flood risks are being mapped (situation analysis), then the consideration of flood risks (risk perception) is examined to determine what risk is considered acceptable and, finally, dialogue with stakeholders takes place on the promising flood risk management measures. In order to funnel all potential measures, the multi-layer safety concept was used and thus categorised in terms of prevention (layer 1), spatial adaptation (layer 2) and crisis management (layer 3). With help of a cost-benefit analysis, measures are quantitatively assessed to evaluate their cost-effectiveness. Subsequently, in consultation with stakeholders, a qualitative assessment is conducted to determine the feasibility, effectiveness, and flexibility of the measures. The identified promising measures are then integrated into potential adaptation strategies.

In the following Table, an overview is presented with studies that focus specially on the unembanked areas.

Table 4: Overview evaluation methods used in literature specially on unembanked areas

Paper	Location	Scale of measures	Method(s)	Remarks
De Moel et. al (2014)	Unembanked areas of Rotterdam	Area and building level	Cost-effectiveness on measures layer 2 of MLS-approach	Full cost-benefit analysis out of scope, other considerations e.g. location characteristics or social impact not taking into account
Gersonius et al. (2015)	Island of Dordrecht	Regional, area and building level	ADM approach (incl. AP's) assessed on technical aspects (i.e. efficiency and cost-effectiveness) legitimacy and social feasibility	No in-depth study on possible alternatives for unembanked areas and not clear on what 'wider benefits' the adaptation strategies are assessed

Van Veelen (2016)	Kop van Feijenoord and Noordereiland, Rotterdam	Area and building level	- Adaptation measures evaluated on performance criteria (flood reduction, cost-effectiveness, social equity, spatial quality, additional benefits, negative side effects on other levels of the system) - Adaptation pathways assessed by MCA incl. spatial quality, cost-effectiveness and other benefits	As indicated by the case studies, the effectiveness of particular measures in enhancing flood resilience is heavily influenced by the unique geographical, hydraulic (such as storm surges or small inundations), and social and spatial conditions,
Pohl et al. (2014)	Kop van Feijenoord, Rotterdam	Area and building level	Cost-benefit analysis including general description by whom costs/benefits of measures are borne	Only looked at benefits from water safety perspective, other social costs or benefits not considered
Adaptation strategies for port of Rotterdam	All ports areas in Rotterdam	Area and building level	Mix of qualitative assessment (i.e. time/flexibility, effectiveness and feasibility) and quantitative assessment (i.e. cost-effectiveness)	Social impacts of measures are often not taking into account

3.8. Conclusion

The (scientific) literature dedicated specifically to the decision-making process for flood risk measures in unembanked areas, as defined in the Dutch context, appears to be relatively limited. Therefore, in addition to a specific focus on unembanked areas, a broader perspective was adopted to explore theories and approaches used in flood risk management. To better comprehend the challenges associated with determining the appropriate set of measures in unembanked area development, this chapter has used a literature review to examine how flood risk management works and the various evaluation methods utilized during the decision-making process.

Firstly, multiple studies indicate that the multi-level safety (MLS) concept, originally designed for areas within the dike rings, is also highly suitable for unembanked areas. Investing in layer 2 (damage reduction through spatial interventions) and layer 3 (crisis management) is more complex due to the involvement of more parties than focusing solely on layer 1 (preventive measures). Nevertheless, it is very rewarding in unembanked areas to invest in the other layers as well. Moreover, the proposal to expand the MLS concept with additional layers for recovery and water awareness aligns well with the challenges faced in unembanked area development. While the MLS approach does not function as an assessment method, it is essential to highlight its appropriateness as a framework for organizing potential measures. The approach can effectively serve as a conceptual guide for adaptation measures in unembanked areas, thus contributing to the decision-making process.

Moreover, frameworks such as adaptive pathways (AP), adaptive tipping points (ATP), and adaptive delta management (ADM) have been used for adaptation strategies in unembanked areas. These resilience-based planning methods offer valuable guidance in the decision-making process and serve as an effective means to facilitate ongoing decision processes by assisting decision-makers in choosing future adaptation options that align with changing environmental and societal conditions.

For unembanked areas, these methods were found to be effective methods to evaluate and select appropriate urban flood adaptation strategies. Instruments like (social) cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), or multi-criteria analysis (MCA), when applied thoughtfully within the framework of adaptive pathways, can contribute to risk-informed decision-making and the development of flexible strategies that can be adjusted over time based on evolving conditions and knowledge.

Now, this chapter was on addressing the first sub-question: '*What evaluation methods are commonly used in flood risk management, and how do these various evaluation methods facilitate the decision-making process in area development in unembanked areas?*'

Social cost-benefit analysis is a widely used tool in flood risk management and spatial planning. This tool serves as an objective means to evaluate policy alternatives or measures, quantifying their effects, uncertainties, costs, and benefits in monetary terms for as much as possible. Different types of CBA (as how the term is abbreviated in the *General Guidance for Cost-Benefit Analysis (ENG) / Algemene Leidraad voor Maatschappelijke Kosten-Batenanalyse (NL)*) do exist, such as a complete CBA (incorporating all social costs and benefits and monetizing them as much as possible) and lighter versions like key figure or quick-scan CBAs. Other evaluation methods, including cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), and impact assessment (IA), are also commonly used evaluation methods in flood risk management.

Nevertheless, there are limitations to the usefulness of CBA in the decision-making process. If the key effects cannot be accurately measured or monetized, a CBA can only provide incomplete information with restricted reliability and relevance. The literature emphasizes the importance of considering non-monetary or intangible effects, like impacts on nature, landscape, historical heritage, and stress from flooding, in CBAs. Despite ongoing attempts, quantifying and monetizing social impacts such as spatial quality remain challenging due to a lack of adequate valuation methods. Moreover, there are no key figures for this matter that could be used for a lighter version of CBA. Yet, studies show that incorporating these intangible effects can provide more robust decision-making on adaptation measures at the local or building level for stakeholders in flood risk management. And this is especially crucial in the development of unembanked areas, where elements such as a direct view of water, the creation of new water experiences, and the preservation of cultural-historic characteristics are often deemed very important.

This is in line with the general guidance for CBA of Romijn and Renes (2013b) that says to '*consider doing a cost-effectiveness analysis (CEA) if all the measures to be investigated have the same (main) effect'* (e.g., the reduction of flood risk) or *'if the main effects cannot be properly measured or monetised, use the principles of CBA as a conceptual framework. This will help to structure the decision-making, but will not result in a CBA and may not be called a CBA.'*

In addition to this, MCA is very useful tool for supporting decision-making on local flood risk measures, as it does not quantify effects in monetary terms but assigns a weight to each effect. However, careful attention must be paid to preventing double-counting of effects, and MCA is less objectively than CBA since decision-makers can determine the weights of criteria. Nonetheless, MCA can be combined with CEA and CBA. However, when combining with CBA, it should be clearly phrased what form of CBA is used, e.g., a 'partial' CBA (i.e., a CBA that solely focuses on (one) direct effect(s) that is/are monetizable, for example reduction of flood risk).

4

LESSONS LEARNED FROM PRACTICE

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4.1. Introduction

To arrive at decisions regarding local adaptation measures, practical insights into the management of flood risks in unembanked areas are essential in addition to theoretical knowledge. Therefore, an examination of lessons learned and best practices is valuable and has been proved to be useful in previous research, for instance, in the application of adaptation pathways in flood risk management (Bloemen et al., 2017).

Furthermore, the possibilities for local adaptation measures (e.g. elevation of sub-areas, land, buildings, wet and dry construction, emergency flood defences, floating or amphibious construction, etc.) are endless. The scale of analysis significantly influences the choice of adaptation measures. The main goal of this study is not to decide out of all possible options what is the best set of measures for a specific area, but is focused on gaining a better understanding on the decision-making process for adaptation measures in unembanked areas. However, through analysis of real-world examples, it will give an idea of the possibilities and could inspire which measures to implement.

Thus, this chapter has a dual purpose. On the one hand, it gives insights into possible measures applicable at different levels i.e. regional, district and building level. This could be used as input for a decision-making tool e.g. possible alternatives in a CBA or MCA. On the other hand, it provides an opportunity to look at how adaptation measures were arrived at in practice.

In the methodology is explained how information was obtained and the reason why those specific cities were chosen. This chapter provides an overview of the results by going sequentially through the different cities. This chapter contributes to answering sub-question 2: *What decision-making methods have been used in recent projects in unembanked areas, and what can be learned from these practical examples?*

4.2. Rotterdam, the Netherlands

As mentioned earlier, adaptation strategies have been developed for port areas, and the municipality is currently formulating adaptation strategies for its urban unembanked area, starting with the Kop van Feijenoord. This subsection will delve deeper into one of these earlier developed adaptation strategies, Merwe-Vierhaven (M4H). However, first a particular policy measure that transcends districts and thus affects all unembanked areas in Rotterdam is discussed: the issue level policy (*NL: uitgiftepeilenbeleid*). There is a wealth of knowledge available regarding the origins and decision-making surrounding the issue level policy, and with an upcoming recalibration, renewed attention is being given to this measure. Prior to delving into these two subjects, it is useful to share the findings of Gebraad et al. (2018), which specifically concentrated on lessons learned from practice in unembanked areas in Rijnmond-Drechtsteden. These lessons are:

1. Increase in economic risk is main consequence of climate change in unembanked area
2. Users and residents of the unembanked area have limited awareness of flood risk and their own responsibility
3. 'Joint fact finding' with all parties, public and private, increases awareness and support for measures
4. A joint climate adaptation strategy is not easy to formulate without a shared view of the acceptable risk
5. Prevention, spatial adaptation and crisis management from the multi-layer safety concept adds value for climate adaptation in unembanked areas
6. There is no 'one size fits all' strategy

4.2.1. Issue level policy

Introduction

As seen in Figure 8 in Chapter 1, one of the measures the municipality of Rotterdam has taken is to use an issue level policy. In principle, the issue level is mandatory of all new developments in unembanked areas in Rotterdam. The policy applies a minimum ground level of +3,60m NAP for non-vital facilities and +3,90m NAP for vital facilities for unembanked areas behind the Europoort barrier (EPK), the Maeslant barrier and Hartel barrier together. Outside the EPK, an issue level of +5,10m NAP applies for non-vital facilities and +5,60m NAP for vital facilities. The issue level (ground level height) corresponds to a probability of occurrence of 1:1,000 years in the year 2100 under an average climate scenario G+ (KNMI scenario of 2006). So with this ground level, a building development therefore has a chance of flooding once every 1,000 years (Rotterdams WeerWoord, 2021b). For vital and vulnerable functions the probability of occurrence is 1:4,000 years in the year 2100 under an average climate scenario G+ (KNMI scenario of 2006). See Table 5 for the total overview.

Table 5: Overview current issue levels Rotterdam

Issue level	Area in front of the EPK	Area behind the EPK	Probability of flood occurrence in 2100
Basic+ level	+5,50m NAP	+3,90m NAP	1:4000
Basic level	+5,10m NAP	+3,60m NAP	1:1000

Sometimes it is not possible in projects to adhere to the intended issue level, e.g. when a project site is adjacent to existing buildings with a lower level. Deviation from the obligation to elevate a site is allowed, provided it can be otherwise guaranteed that real estate is protected from water up to the issue level. This is mainly due to the need to comply with provincial policy on the loss-of-life risk. Alternatives are in principle consulted within the municipality with the ‘issue level committee’, currently consisting of only one person (Internal document municipality of Rotterdam, 2023). Having the possibility to deviate from the issue level provides flexibility. In case there is a desire among initiators not to make real estate 'dry or wetproof', this should be discussed by the initiators with the province of South Holland (Van Barneveld et al., 2018).

History of issue level policy

Until a few years ago, issue levels in the unembanked area were determined based on advice from Rijkswaterstaat. In 2012, the Province of South Holland drew up new policy for developing in unembanked areas. In the past, the municipality translated this advisory height into the issue level (Van Barneveld et al., 2018). Thus in practice, advice on issue levels had been going on since 2012, however, the current issue levels were established in municipal policy in 2018 (Internal document municipality of Rotterdam, 2023). Since issue levels have been advised by different parties, there are different heights visible in the city (Internal document municipality of Rotterdam, 2023). Figure 19 provides an overview of the differences in determination of issue levels.

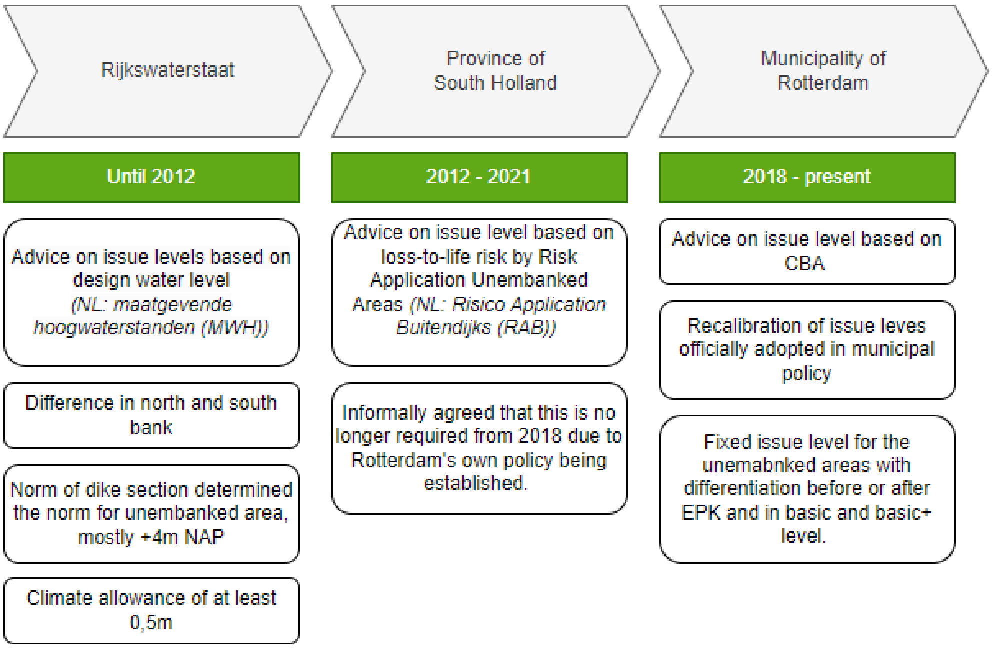

Figure 19: Progress of issue levels in Rotterdam (Adapted by author, based on internal document municipality of Rotterdam, 2023)

For their calculations, RWS used design water levels (*NL: maatgevende hoogwaterstanden, MHW*) from the hydraulic preconditions with an allowance for climate change for the year 2200. The north of Rotterdam had a higher standard (1:10,000 years) than the southern part (1:4,000 years) due to the high value and potential impact of the hinterland. The climate allowance should be at least 0,5 metres.

In 2012 the Provincial Structure Agenda for South Holland established a standard (reference value) for the risk of casualties in unembanked areas which only applies to new developments. This stipulates that the probability of death due to flooding should not exceed 1:100,000 per year (this is equal to the national safety requirement for inner dike areas in the new water safety policy of 2017). Moreover, the Risico Applicatie Buitendijks (RAB) *(Eng: Risk Application Unembanked Area)* was created by the Province of South Holland and was an online tool that was available for all municipalities within the province. The RAB not only mapped the loss-to-life risk, but also the potential number of people affected by 'functional failures', for example in case of power failure or if roads are no longer passable after a flood (Elshof et al., 2014). In addition, it was possible to compare the effects of different measures (Van Barneveld et al., 2018). However, the RAB did not calculate the risk of economic or environmental damage after a flood, while this is much more decisive for the total risk (Elshof et al., 2014). Nowadays, the RAB is no longer available because it was underused and updating the tool was not a worthwhile investment given the low number of users (Konings, internal communication, 2023). Based on the reference value and by usage of the RAB, the issue levels by the Province of South Holland were derived. Figure 20 provides an overview of the different issue levels in different areas in Rotterdam as advised by the Province of South Holland.

Figure 21 shows that RWS recommended the highest issue levels (orange line) and the Province of South Holland gave the lowest issue levels (dark green line). This is because it only looks at loss-to-life risk (Van Barneveld et al., 2018). Another characteristic is the relatively small difference between the levels of the various locations, both for the RWS and province of South Holland levels. This is due to the fact that both levels are based on the normative high water levels in which there is little fluctuation per location (Van Barneveld et al., 2018). The biggest difference is caused by the Maeslant barrier: at sea the water levels are much higher.

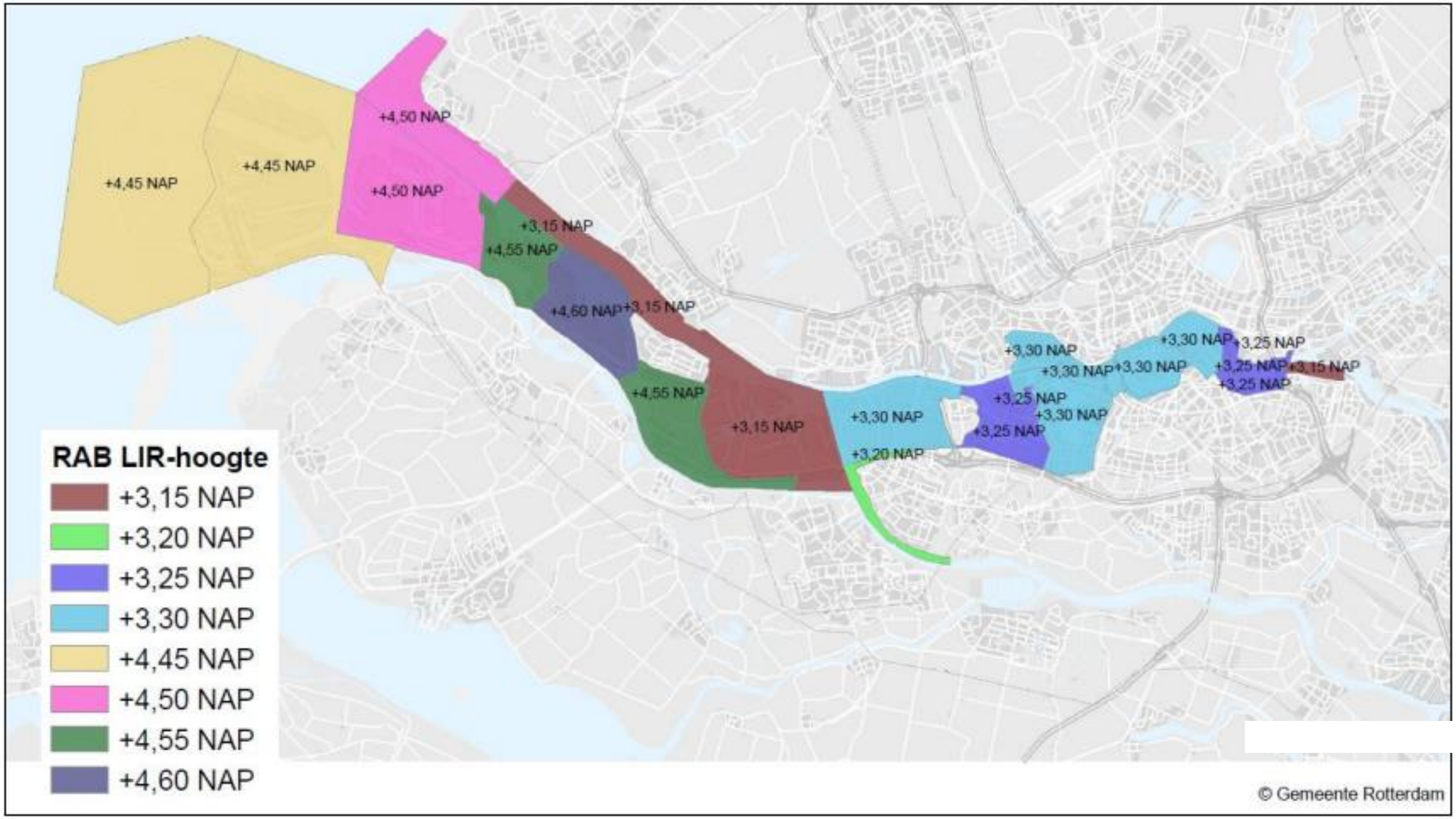

Figure 20: Derived heights based on Local Individual Risk (LIR 10-5) and the Risk Application Unembanked Area (RAB, Province of South Holland) (Trouwborst et al., 2014)

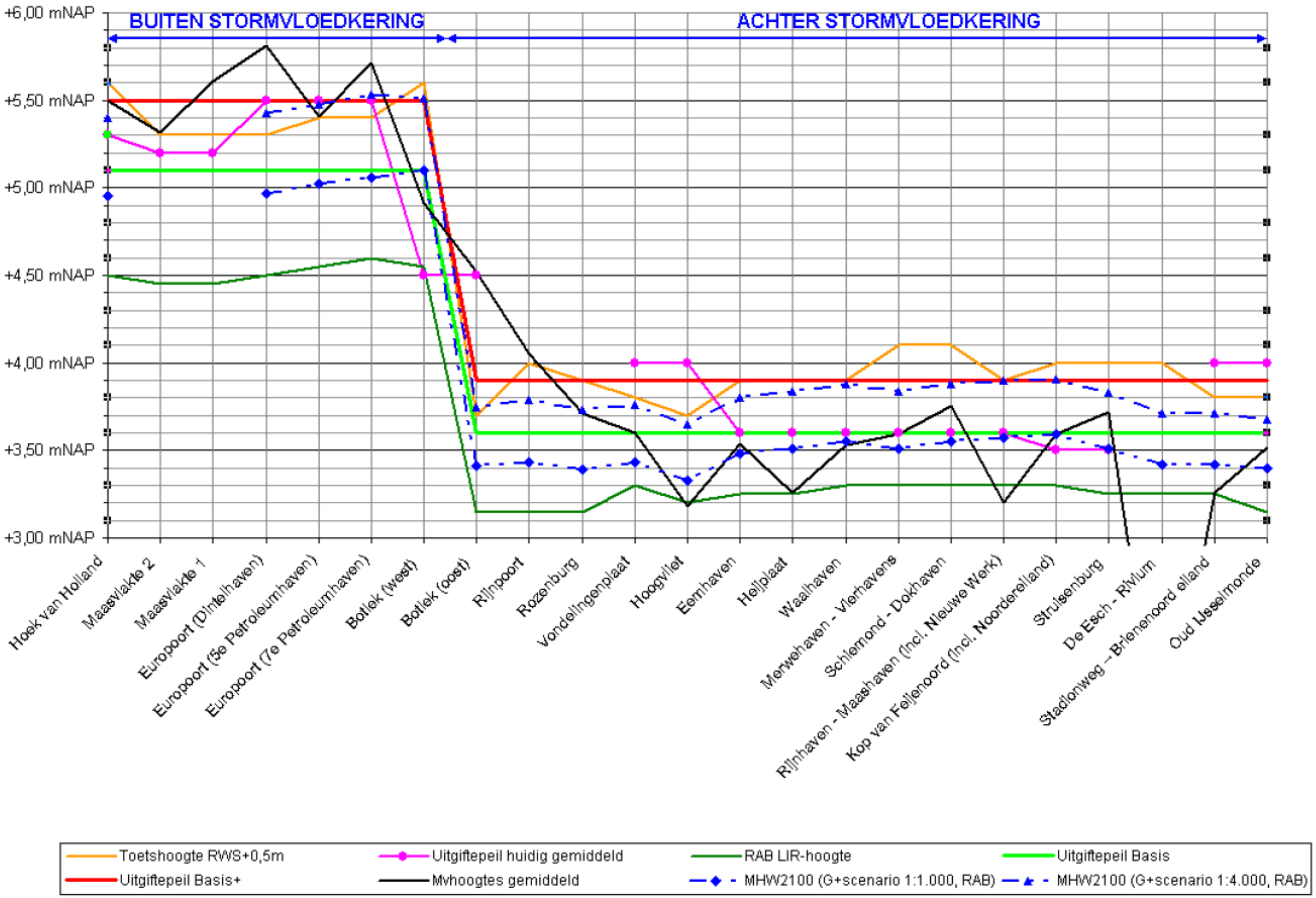

Figure 21: Elevations and levels outside and behind storm surge barrier Maeslant barrier: issue levels (current, old/RWS, basic and basic+, levels cf provincial policy (RAB LIR), design water levels (MHW) in the year 2100 for different repetition times (Trouwborst et al., 2014)

The Expertise Network for Flood Protection (ENW) has advised to further elaborate the theoretical underpinnings of the issue level policy and conduct a cost-benefit analysis (Mooyaart & Schoemaker, 2017). Thus, the current used issue levels are determined by a form of CBA that addresses the trade-off between site elevation and flood risk. Ultimately, therefore this could be termed as a partial CBA, since only one effect is considered i.e. reducing flood risk through site elevation.

The issue levels are still excluded from subsidence, waves and seiches. The issues levels will be recalibrated as new climate scenarios will be published by the KNMI in 2023 in which is expected that sea level rise will go even faster than previously predicted (Koninklijk Nederlands Meteorologisch Instituut, n.d.). There is still a lot of scientific discussion here about assumptions of damage (numbers) and costs of measures (Van Barneveld et al., 2018).

Evaluation and recalibration of issue levels

In practice, one of the complex things is to make the issue levels legally binding. The policy of the Province of South Holland identifies the zoning plan as an useful instrument to secure implementation of the issue levels (Van Barneveld et al., 2018). Also, municipal policy around (recalibrated) issue levels primarily draws on the zoning plan for legal assurance (Van Barneveld et al., 2018). However, this will require a lot of long-term commitment from colleagues working in the water department (Internal document municipality of Rotterdam, 2023). An evaluation report on the recalibration of issue levels mentions other possibilities e.g. issue levels can be included in environmental permits, anterior agreements and the future spatial planning and environment plan (Internal document municipality of Rotterdam, 2023).

A draft version of the rules of thumb for construction in Rotterdam *(NL: De Rotterdamse vuistregels voor bouwen),* which is a sum of legislation, policies and ambitions pursued in the city, considers the unembanked areas. It is structured as a traffic light scoring table wherein each theme can be assessed on certain criteria. For building in unembanked areas, for instance, this includes building at the right the issue level (Gemeente Rotterdam, concept of internal report, 2023).

Moreover, both building and construction authorities *(NL: bouw- en woningtoezicht, BWT)* and designers seek greater clarity regarding deviation options if the set issue level cannot be met. Additionally, there is a need for increased transparency concerning the costs associated with these alternative measures, potentially through the use of benchmark figures (Internal document municipality of Rotterdam, 2023).

Besides legal assurance and better definitions being areas of concern, there are a few other interesting findings from the evaluation. The underlying substantive methodology of using a CBA is grounded, as it has also been underlined by the ENW. However, things like non-monetary effects like image are now not included in calculating issue levels. Also, the policy regularly clashes with other policy objectives, both in terms of incorporation, lack of clarity on responsibilities and associated funding. One major drawback of elevating sites to the appropriate issue level is that risk awareness among residents and users is not raised. An alternative could be to protect the area to the desired safety level (i.e. issue level) in some other way, such as by dry- or floodproofing buildings or by placing moveable quays in the public space.

According the current schedule, the recalibrated issue levels can be adopted by the municipality in 2024. The new KNMI climate scenarios of 2023 will be used for the recalibration. Discussions and workshops were held with asset managers to identify the consequences of higher issue levels for various assets. It is also considered to look at 2125 instead of 2100, as new developments have an average life span of 100 years.

Preferred order of measures in Rotterdam

Besides the issue level policy, the municipality of Rotterdam has drawn up a preferred order of measures on how to take high water levels into account, see Figure 22 (Team Hoogwater, internal document '*Redeneerlijn buitendijks bouwen en beheren',* 2023).

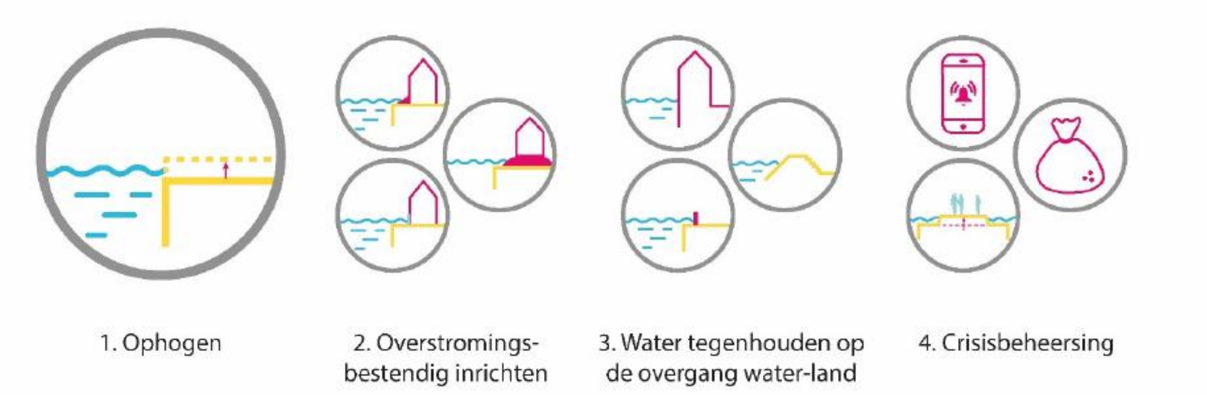

Figure 22: Preferred order of measures in Rotterdam (Team Hoogwater, internal document 'Redeneerlijn buitendijks bouwen en beheren, 2023)

Importantly, this order of preference is only viewed from the perspective of flood risk management and not from other interests. Elevation, to which the issue level policy applies, is seen as option 1 since other options can be used in addition. Connection with existing buildings and public areas, spatial quality, drainage of rainwater within the area itself, CO_2 - emissions, drought (groundwater is relatively deeper, making greening more difficult) and costs are reasons to go for other options.

After elevation, the option of flood-proofing follows. This means that the area is allowed to flood, but it can withstand it. Main routes and property do stay dry with modifications to prevent damage. This option embraces the idea of living with water.

This is followed by the option of withholding water at the transition from water to land. Water is held back with dikes, (temporary) storm walls or buildings. This option is the least adaptive from a water safety point of view, because going back to options 1 and 2 will be difficult in the future. These options do provide safety for all inhabitants behind the barrier. However, the flood defence must be managed and maintained. In addition, the risk of high water, which currently lies with the residents/users, will shift to the municipality. It can also form a barrier between land and water, and rainwater runoff towards the river is a concern.

Finally, option 4 is crisis management. This is about better (organisational) preparation for a possible flood and crisis management during an incident. The measures involved range from warning, closing quays, placing sandbags to creating evacuation areas.

4.2.2. Adaptation strategy for Merwe-Vierhaven

As for the other port areas in Rotterdam, an adaptation strategy has been formulated for Merwe-Vierhaven (M4H), This is an interesting case study area, as the unembanked area will be transformed from a port area into a new function for living, working, education and recreation. Merwehaven, part of M4H, is going to be turned into an innovative urban district with attention to historic past and the original structure of old city harbour. According to the Merwehaven Masterplan, the first phase (2023-2033) consists of the redevelopment of the Marconistrip and Merwepieren into a residential area with a mix of housing types and a mix of working and (social) facilities. In this phase, 2,500 new homes are planned for Merwehaven and a total of about 5,100 homes are expected until 2040 in the whole M4H (Gemeente Rotterdam, 2023).

To explore possible measures and initiate the process of identifying suitable flood risk measures, several steps were undertaken. Firstly, the MLS concept was employed, and the starting point for an inventory of measures was derived from the previous adaptation strategy for the Waal-Eemhaven. Measures that were not deemed promising for M4H were excluded from further assessment. A quantitative evaluation of measures was carried out based on a cost-benefit analysis, followed by a qualitative evaluation considering the factors time/flexibility, feasibility, effectiveness, and spatial identity. This combined approach was used to select the most promising measures. The cost-benefit analysis focused on identifying the most cost-effective measures for each pier. This entailed assessing the expenses associated with measures to safeguard the entire pier against flood risks that occur less frequently than a 1/1,000 probability per year by 2050, as well as considering the benefits in terms of economic damage reduction due to these measures. Only measures designed to protect the entire pier were included in the analysis. Regarding the timing of implementing these measures, the approach was to do so when the flood risk for a pier is considered unacceptable from the perspective of inland water safety. An evaluation framework for this is detailed in the report.

For M4H, two possible adaptation strategies have been formulated for flood risk management: 1) 'keep water outdoors' and 2) 'living with water'. The adaptation strategy was formulated earlier than the adoption of the Masterplan Merwehaven, but the strategies took into account that the port area possible would be transformed to a mix of living and working. Figure 23 provides an overview of the M4H, showing the dotted line as a primary flood defence, which also partially functions as an evacuation route.

Figure 23: Visualisation of the main concept choices in the adaptation strategy. Green: 'living with water' and white: 'keep water outdoors'. The black arrow and the green arrows visualise the evacuation routes, blue arrow points out Marconistrip and the red arrows point out the Merwepieren (Adapted from Van Der Visch et al., 2019).

Interestingly, for the Korte Merwepier and Lange Merwepier (indicated by red arrows in the Figure 23), there is a deliberate deviation from Rotterdam's currently applicable issue level policy. This fits the theme of 'living with water', in which the area can (partly) flood and damage can be limited with water-robust buildings such as dry- and wet-proof construction or building on piles. The construction of a tidal park along the Marconistrip (indicated by blue arrow) also fits in with the identity of M4H and has a communicative function for living in unembanked areas. Communication on risks, responsibilities, and self-reliance is essential in this strategy, as residents and users are responsible for damage themselves; there is a need for ongoing awareness and maintenance of flood risk awareness. There is a risk that without actual flooding, awareness of self-responsibility may decrease, which emphasises the importance of continuous communication and rules to promote water-safe behaviour and area design. As part of the adaptation strategy, some form of CBA has been executed, see Figure 24. As well, cross-section of the streetscape have been made including the proposed promising measures, see Figures 25 and 26.

Maatregel	Laag 1	Laag 2		Laag 3		
	Kades & glooi-ingen ophogen	Ophoging	Waterrobuuste bebouwing	Noodkering	Gebieds-noodplan	Noodvoor-zieningen
Korte Merwepier						
Baten	454	382	382	217	45	52
Kosten	1.080	95	578	720	100	300
Baten-kostenratio	0,4	4,0	0,7	0,3	0,5	0,2
Lange Merwepier						
Baten	801	674	674	382	80	91
Kosten	1.943	253	1.868	1.295	100	300
Baten-kostenratio	0,4	2,7	0,4	0,3	0,8	0,3
Marconistrip						
Baten	711	598	598	339	71	81
Kosten	593	346	1.290	395	100	300
Baten-kostenratio	1,2	1,7	0,5	0,9	0,7	0,3

Figure 24: Costs and benefits analysis of measures in euros (green is a positive benefit-cost ratio and red negative) (Adapted by author from van der Visch et al., 2019)

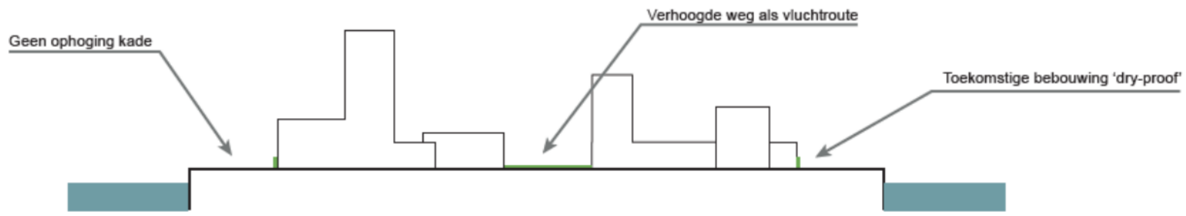

Figure 25: Cross-section of the Korte Merwepier with proposed promising measures (van der Visch et al., 2019)

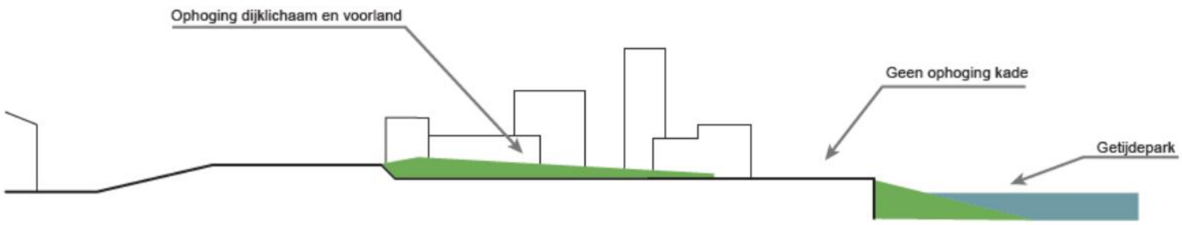

Figure 26: Cross-section of Marconistrip with proposed promising measures (van der Visch et al., 2019)

As seen from the quantitative analysis, for Korte Merwepier and Lange Merwepier, water-robust construction has a negative BCR and raising the area has positive BCR. For Marconistrip, raising quays and slopes has a positive BCR. Despite the results of the CBA, a deliberate choice is made to advice different measures that fit more with the 'living with water' philosophy, see Figure 25 and 26. As the report states for Korte Merwepier and Lange Merwepier: '*Because of its location on/in the water, the theme 'living with water' fits well with the spatial identity of this area….. Here, protecting the townscape outweighs cost-effectiveness (as this option is more expensive than site elevation)"* (translated from van der Visch et al., 2019). And for Marconistrip it say that '*the existing sheds in this area are culturally and historically iconic. For this reason, it has been proposed to opt for the water-robust building measure here'* (translated from van der Visch et al., 2019).

Ultimately, considering the explanation of different evaluation methods presented in Chapter 3, it could be argued whether the term 'cost-benefit analysis' in the adaptation strategy should be more accurately labelled as a CEA or partial CBA. It leans more towards a CEA, as in a CBA, alternatives would be examined in comparison to the baseline alternative (i.e., deviating from the current issue level policy in Rotterdam), as described in the general guidance from Romes and Renes (2013b). Instead, for each pier, the focus is on the cost-effectiveness of a measure. However, in a CEA, as mentioned in Chapter 3, the effects are not monetized (which is the case here), and therefore, the analysis could also be classified as a partial CBA. In this analysis, effects are expressed in monetary terms, but only one benefit is considered: the reduction of flood risk. As can be seen, there is a grey area between methods, making it difficult to use the right definition.

The key insight from this case study is that the combination of qualitative and quantitative methods is an effective approach for robust decision-making in the development of an unembanked area. The results from the report indicate that conducting a quantitative analysis for cost-benefit considerations in reducing flood risks is insufficient for robust decision-making in unembanked area development. If the BCR ratios were the sole determinant, choices of proposed measures would have been different that would, however, from a flood risk perspective be more economically efficient. Therefore, integrating the quantitative method with a qualitative assessment allows for consideration of the location characteristics of the area and other important values. This approach ultimately leads to the desired tailor-made approach for the area development in the unembanked area of Merwe-Vierhaven.

4.3. Vlaardingen, the Netherlands

Context

Vlaardingen, like Rotterdam, is located in the Rhine Estuary-Drechtsteden region and, due to its location next to the New Meuse river, also has urban unembanked areas. In the Rivierzone (as the area is called) the planned urban development consists of around 3,000 new houses. Programma Ontwikkeling Rivierzone *(ENG: Development Program River Zone)* consists of three areas: the Koningin-Wilhemina haven (KW-haven), the Maaswijk and Zuidelijke Binnenstad (Gemeente Vlaardingen, n.d.-b). KW-haven, which includes the peninsula Eiland van Speyk (550-600 new houses), and the Maaswijk are part of the unembanked areas of Vlaardingen (Gemeente Vlaardingen, n.d.-a). It is an old port area with monumental warehouses, sheds and storage tanks. Its direct location on the water makes it an attractive area, but at the same time brings challenges against flood protection. In recent years, it floods as many as five times a year and the water repeatedly stands up to 80 centimetres high from the quay to just below the window frames (Titawano, 2021). Because it floods annually, residents and municipality are geared up to install bulkheads or evacuate from the area. Floods are often over after 24 hours, but the water can still cause damage during that time.

Figure 27: Project area urban unembanked development Vlaardingen (Boon et al., 2022)

However, this happens even more and more frequently, leading to deterioration and impoverishment of some of the heritage. At high tide, the quays alongside are inaccessible to emergency services (Boon et al., 2022). A redevelopment plan for public space is necessary to enable proper incorporation of embankments, ensure spatial quality and keep the quay usable for the intended transformation to living, working and recreation (Boon et al., 2022).

The company Arcadis was asked to draw up a sketch design and substantiated cost estimate for the redesign of the KW-haven public space, taking into account the spatial incorporation of the required flood protection measures. To arrive at this, a variants study was drawn up of possible flood protection measures in the planning area. The Veiligheidsregio Rotterdam-Rijnmond (VRR) *(ENG: Safety Authority Rotterdam-Rijmond)* had set a hard condition that the addition of housing and possible redevelopment of existing properties, may only take place if the quays (and thus the properties) are passable and accessible at high water.

Based on this requirement, all variants at building level were rejected, as emergency services must be able to access the building anyway, and therefore measures in public space are required. Measures at building level can always be added later, but are out of the scope of research from Arcadis.

Setting protection levels

For the development of the area, two different protection levels have been set:

- <u>Residential</u>
  - Return period: 1:1,000 years
  - Vision year: 2125 (estimated end-of-life of new houses to be built)
  - Desired flood height of at least +3,70m NAP
- <u>Public space</u>
  - Return period: 1:100 years
  - Vision year: 2065 (end of technical lifespan of the flood defence system to be constructed)
  - Protection level of +3,40m NAP
  - Varying per location: to include seiches and water overtopping there is a required surcharge of 10-40 cm

Transforming existing buildings and new construction requires a floor height of at least +3.70m NAP. For existing buildings, this means that the ground floor may not have residential functions, but can serve as storage, garage, etc.

A different level was deliberately chosen for public space, partly because the technical elements of the flood defences have a lower lifespan and a lower return time was accepted. An important factor is that a different choice was made, because the starting point for the project was to create a liveable environment for people in the area. For instance, if a very high quay is built, or an very high technical element is added in the public space, the character of the harbour disappears. The feel of the old harbour has a lot of charm and therefore had to be preserved.

Decision-making process and costs distribution

The '*Uitgangspuntennotitie KW-haven'* sets out a collection of starting points and assumptions for various themes. These starting points serve as input for the elaboration of the draft design for KW-haven and the associated cost estimates. These include, for example, function of the area (experience of harbour and water), history and culture (protected cityscape), greenery, climate and biodiversity.

<u>Round 1</u>

By elaborating on all relevant features emerging from the area analysis and *Uitganspuntennotitie KW-haven*, a total of 5 main criteria were defined. The different variants were assessed on these main criteria.

Table 6: Round 1 weighting table variants for redevelopment of KW-Haven (based on internal report Arcadis, 2022)

Criteria	Subtheme	Weight
Spatial quality	Spatial quality	5
	Spatial / water experience	4
	Functional design	2
Technical elements	Cables and pipelines	1
	Emptying behind the barrier	2
	Quay construction	3
(Water) safety	Failure probability	8
Management and maintenance	Management and maintenance	5
Costs	Costs	5

They looked at permanent, temporary solutions, combinations of these and cross-area solutions. They then looked at the strength, weakness, cost (rough estimate indicating scale) of all the solutions considered to conclude which variants to be further considered. .

The main conclusion is that area elevation and jacking up existing buildings proved technically as well as financially unrealistic. Closing the harbour was also not an option, as costs and management were high and it was considered undesirable and unrealistic to stop commercial shipping on the north side.

Round 2

The remaining variants from the first round were all assigned a score. The variants are further considered in this chapter to arrive at a single preferred variant. After the screening on the five main criteria, the remaining variants were assessed on criteria with lesser impact. These criteria are: traffic, sustainability, future-proofing and implementation, all with an equal weighting factor.

Table 7: Round 2 weighting table variants for redevelopment of KW-Haven (based on internal report Arcadis, 2022)

Criteria	Sub theme	Weight
Traffic	Traffic adaptability	1
Sustainability	Biodiversity	1
	Climate adaptation	1
Future-proof	Spatially adaptable	1
	Adaptability height up to 2065	1
	Adaptability height after 2065	1
	Adaptability height after 2125	1
Implementation	Feasibility	1
	Planning	1

In summary, the solution for the area is summarised as follows (see Figure 28):

- Psychical barrier to +3.40m NAP behind the quay
- Dry roadway and buildings
- Wide quayside strip as a stroll area with terraces
- Lockable pass-throughs
- Barrier can be max. 1,2m height relative to pavement

An important spatial argument here is that the water remains visible when walking along the barrier, as the wall cannot rise higher than 1.20m. The area will ultimately not be raised anywhere, at most floors in the property itself. A factor in this was that it was not realistic to raise monumental properties. The failure probability of the lockable pass-throughs should be calculated in further technical study. There should be management company that becomes responsible for maintenance and testing of the walls. This solution has the disadvantage that it may create a false sense of security for people behind the barrier, as it remains officially unembanked area.

In terms of costs, Vlaardingen has used financial support from the national government by applying for the '*Woningbouwimpuls*'. So it is assumed that the redevelopment will be paid for by the municipality and national government funds (such as subsidies). The municipality did decide, in coordination with entrepreneurs and property owners in the area, that part of the responsibility would also be placed on them, as this goes beyond the government's duty. Follow-up research into legal aspects on how to enforce that costs are partly paid by the property owners and users, still needs to be done by the municipality.

It is not possible to recover part of the costs through land exploitation (the municipality charge money for a change of function in the zoning plan), as the municipality does not own any land in this area. A full CBA was outside the scope for this area development, as the main assumptions were that the requirement of the VRR regarding accessibility for emergency services and experiencing the harbour and the water would be met. The value preservation of monuments was not assigned a monetary value.

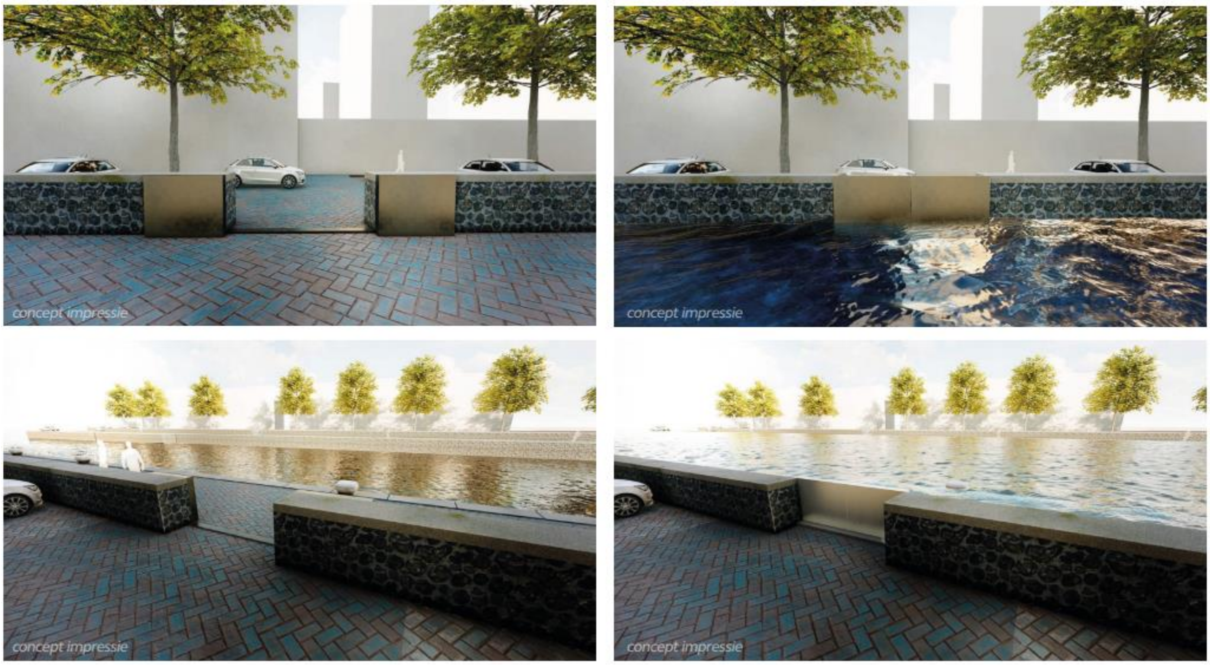

Figure 28: Concept impression of final solution for KW-Haven Vlaardingen during low and high water tides (Kruijt, 2022).

4.4. Zwolle, the Netherlands

Context

Zwarte Waterzone, part of the municipality of Zwolle, is located within the IJssel-Vecht delta. A characteristic feature of the development locations is that they are positioned in unembanked areas. Living with water, flood risks and climate change are therefore a major concern in the development of the area. The municipality has the ambition to transform this area and its location in the floodplains offers many opportunities for a distinctive and attractive living and working environment. The plan area is directly connected to the IJsselmeer. As a result, the area has different water levels with a variation of almost 4 metres (fluctuating from -1m NAP and +3m NAP in extreme situations). The area is part of the primary water system and it acts as a buffer during high water and ensures sufficient flow. See Figure 29 for overview of the area. The blue marked areas are unembanked and are planned to redeveloped.

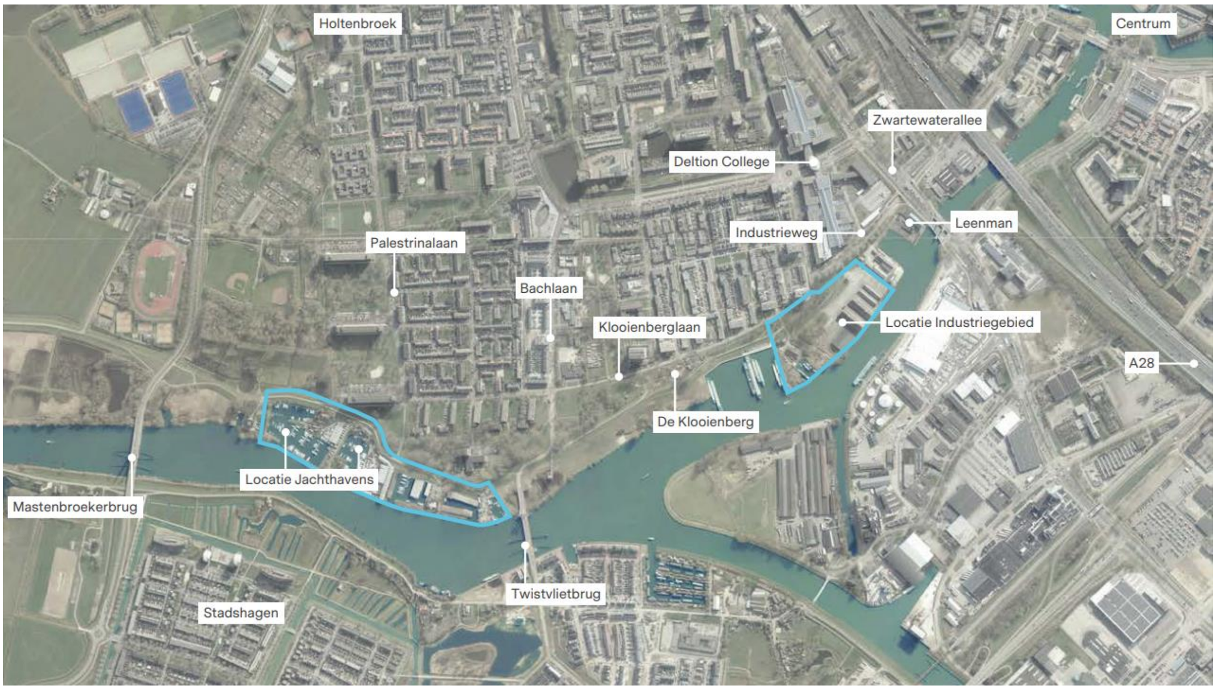

Figure 29: Intended sites for area development in unembanked areas of Zwolle marked in blue (BPD | Gebiedsontwikkeling, n.d.)

Setting requirements and conditions

The municipality has created a vision for the development of Zwarte Waterzone. This was translated into requirements and boundary conditions to develop in the unembanked areas (Gemeente Zwolle, 2021):

1. Reducing flood risk with function-oriented design
    a. Vulnerable and vital functions receive extra protection, other functions are allowed to flood occasionally and shallowly. Residential gets highest level of protection, but water is allowed on the quay. This avoids elevating the whole area, but instead considers smart spatial planning.
2. Climate-adaptive and future-proof design
    a. Accelerated climate change and/or adjustments in the water system of the Vecht, IJsselmeer and Sallandse Weteringen will not lead to additional social costs or bottlenecks in the future. This is related to the building heights.
        i. The developer should clarify the robustness of the design and demonstrate that a future increase in extreme water levels to +3.5m

NAP (upper limit scenario) will not lead to significant (social) costs and damage to vital infrastructure. The municipality is anticipating on future regional choices about the IJsselmeer and considers effect of climate change, as they already know it will affect water levels in Zwolle. The current used number is based on statistics of water levels and return periods and includes a future-proof buffer. All in all, the +3.5m NAP is established as safety level for designing the area. Note, this does not mean that all houses need to be placed at this level, but up to this (extreme) water level there should not be significant social costs.

3. Sufficient room for water
    a. The functioning of the water system must not be impeded now or in the future. On balance, the storage and flow capacity of the water system improves so that climate change can be absorbed without problems.
        i. According to the Large Rivers Policy Directive, Zwarte Waterzone has the same exemption as Rotterdam. The area does not contribute to the flow capacity of the river and has no function here, so formally Rijkswaterstaat does not set any requirements for the development site (exemption). Despite this, Zwolle has said that the developments should not influence water capacity in the area. This has translated into the requirement to maintain the current buffer capacity, and to aim for expansion of 10% (around 20,000 m3).
4. Action perspective and evacuation routes
    a. It must always be possible for users and residents to leave the area at high water. In addition, the area must be easily accessible to emergency services (also) in the event of flooding.
5. Creating awareness
    a. Part of plan development is clear communication and user awareness of their own risk for flood damage in unembanked areas

The requirements and boundary conditions are inspired by the new proposed extended MLS concept as shown in Chapter 3 in Figure 13.

It emerged from the interview with the municipality of Zwolle that requirement 3 generated the most discussion and proved to be the most complicated condition. Since area development takes place within a limited area, it turned out to be difficult to justify the benefit of the 10% additional storage space. However, when looked at the system level, it can make a major difference. Despite the fact that the requirement was demanding in terms of needed space, Zwolle has stuck to the requirement, partly with the justification of taking responsibility itself and not depending on or shifting problem on other parties in their water system.

In doing so, the interview revealed that the playing field for developments in unembanked areas is difficult in itself. The municipality's requirements were announced when the parliamentary letter of *Water en Bodem sturend* was just published. In addition, the requirements and areas for which RWS exempts construction and does not require permit application may be reviewed. This creates uncertainty as to whether future construction will be allowed at all in Zwarte Waterzone.

Laying down long-term ambitions in regulations is perceived as difficult. Project developers were initially positive to build here, despite the requirements laid down. However, facing changing market conditions, including a sharp rise in construction costs, increase in (mortgage) interest rates and inflation, make the current plans unfeasible for developers within the frameworks set in 2021 (Gemeente Zwolle, 2023).

What is interesting about this development is that jointly with the area development, the dike will be raised to +3.3m NAP. The design requirement to access roads and floor levels in the unembanked area (+3.5m NAP) is therefore 0.2m higher. The philosophy behind this is that people do not necessarily need to evacuate from the unembanked area in case of high water, even more, part of the lower-lying neighbourhood could evacuate to this area. And given the lifetime of the houses (70-100 years), it makes sense to build it higher now rather than having to raise it in the future.

Decision-making process and costs distribution

To arrive at the conditions, all parties (project developer, safety authority, province, water board, etc.) were consulted and this was later adopted by the municipal council. Project developers can flesh out the requirements themselves. The municipality is working together with BPD | Bouwfonds Gebiedsontwikkeling and BEMOG Projekt Ontwikkeling. The municipality itself is also considering its own role; is this mainly a reviewing role or will it actively participate in the design process?

So far, a cost-benefit analysis is not used in Zwolle, but it was indicated during the interview that it could be an interesting tool to determine the cost-effectiveness of measures. In Zwolle, the five principles have been used to contemplate potential measures for implementation. The municipality has expressed its intention to continue working with these five principles, aiming to maintain control over the rationale behind specific choices, aligning them with their ambitions. Ultimately, these principles were intended to be utilized in the decision-making process through a multi-criteria analysis to arrive at the final set of proposed measures. However, this process has currently stalled as the developer has withdrawn, preventing the assignment of weights to specific criteria from taking place.

In addition, although less stringent in the requirements, it is expected that liveability for people in the adjacent embanked area (not the most affluent neighbourhood) will be improved. The municipality is therefore looking favourably on these plans. From a broader social point of view, these redevelopments in unembanked areas will make the entire area more attractive and improve spatial quality, benefiting the neighbourhood behind the dike as well.

In this project, the costs of new buildings are for the developer. It is to be expected that this will be passed on to future users. However, achieving affordable housing is currently an issue in the Netherlands. With a target of at least 30% social housing to enforce affordable housing, these plans are not financially feasible and there is little room to deviate from this rule. To meet this requirement, more floors could be added to buildings, but this was not seen as desirable from a spatial point of view.

4.5. Copenhagen, Denmark

Context

Recent storm surge occurrences, coupled with ongoing discussions on climate change and rising sea levels, underscore the critical importance of coastal protection measures in Denmark (Faragò et al., 2018; Hallegatte et al., 2010). Just like the Netherlands, cities in Denmark are working on topics like climate adaptation, climate resilience buildings, water management and coastal protection (DI - Conderation Of Danish Industry, 2014). Although Denmark has a different water and legal system from the Netherlands in which no explicit distinction is made between inner dike and unembanked areas, it is still interesting to see how they deal with coastal protection against sea level rise and how they come to decisions on measures. In 2011 a climate adaption plan was made considering the biggest threats for the city, e.g. heavy rainfall, heat islands, sea level rise. In 2016, the Copenhagen City Council commissioned a storm surge plan for the city, outlining a primary strategic approach for storm surge protection, specifying the level of protection, and detailing the associated legal and financial frameworks (City of Copenhagen, 2017).

The following paragraph is based on the City of Copenhagen (2017) plan for a storm surge plan. The city of Copenhagen, and surrounding municipalities like Hvidovre, Dragør and Tarnby, should be protected against storm surges by an outer protection scheme, protecting the harbour and the outer coasts with barriers, dikes and floodgates, see Figure 30. If Copenhagen is not safeguarded against storm surges, it is predicted that the city will suffer damages of between DKK 7.3 and 11.8 billion over the next 100 years. Estimated construction costs for the flood defences are DKK 3.5 billion (plus 2% yearly maintenance expenses). From a socio-economical perspective, protection from the south is most favourable, while storm surge impact mainly depends on the actual sea level rise. So the plan exist of measurement along the harbour and at an over-all strategic level the idea is to protect the whole area. First, the south is protected and the process for the dike trace in the north is now being discussed.

Figure 30: Adaptation strategy for the region of Copenhagen and surrounding municipalities (City of Copenhagen, 2017)

Decision-making and costs distribution

An important note the plan suggest is to that the strategy for Copenhagen's Harbour should be integrated with future plans for area developments and usage of the harbour. In combination with urban development, Technical installations should be considered in conjunction with urban development and it should be investigated how flood measures harmonise with future plans and existing qualities of the city. Local context should be taken into account and solutions should, when possible, offer new qualities for the city as a whole.

Also, an interesting insight is that the southern part of the Ullerup dike, will be in front of the dike. This causes a complex situation in which a different protection level applies on one side of the dike than on the other. This choice was made because the airport a higher level of protection than the municipality of Dragør. Copenhagen, including critical infrastructure like the public transportation systems, airport, energy plants, harbour, is protected against a storm surge with a probability of 1/1,000 years in 2100. In Dragør, via local projects they are working to protect the area for a storm surge that occurs 1/100 years.

In Denmark, people have traditionally been responsible for flood risks themselves. As a result, people are also very aware of the consequences of sea level rise and how it may affect their properties. Municipalities are in conversation with citizens about the threats from the sea, and indicate that they look positively on living so close to the sea and accept the risk of flooding. Since people indicate that living near the sea is considered very enjoyable, coastal protection will have to take into account spatial planning so that a high wall is not placed in front of someone's house.

Cost-benefit analyses are also currently being used to make trade-offs in measures. For example, an analysis was done in 2019 on the consequences if the metro system were to shut down due to high water. Both interviewees argue that it could be interesting to include social aspects such as nature, cultural heritage and mental health problems in the event of flooding, but agree that it is difficult to quantify these aspects.

There is close cooperation with the state, several municipalities, (critical infrastructure) companies and residents. As they all see the urgency and are aware of the risk, companies and residents are willing to pay their share of the bill. In principle, the bill ends up with the property owners involved, and that would also be the only reason why a party like the municipality takes on part of the financing in the first place. Nevertheless, it remains a struggle to determine how much have to be paid by which party. For example, with so many households involved, that all experience benefits from a storm surge barrier, the question is how to make an equal and fair distribution among stakeholders. In addition, in smaller municipalities like Dragør, complaints are received from residents about what they consider a reasonable price for protection measures. In this, the legislation in Denmark gives municipalities the freedom to look at whether they set the price based on how exposed someone's property is to a storm drain, or to look at how valuable someone's property is. Next to a cost-and-benefit analysis, there should be a framework to decide on a reasonable and justifiable price for stakeholders.

Finally, two interesting things that emerged from the interviews. In Dragør, piles are being used on which would be indicated what the water height would be in case of a 1/100 and 1/500 year storm surge. By presenting it in such a visual way, people get a better understanding of what the flood would entail. Moreover, it is noted that in Dragør, there is a difference in the younger and old generation when it comes to how flood risks are perceived. The old generation is more likely to fear loss of value of their property, while the younger generation fears never being able to live in that area at all or never getting their property sold because of flood risks.

4.6. Hamburg, Germany

Context

Hamburg is renowned for its approach to floodproof construction, climate adaptation, and sustainability. Due to its location on the Elbe River and its open connection to the North Sea, Hamburg is strongly exposed to the forces of the tides and regularly faces flooding in parts of the city. To prevent flood damage, significant investments have been made in recent years in multi-layer safety measures, with a strong focus on climate adaptation and mitigation (Mesters et al., 2015). Hamburg Hafencity is seen as one of the international examples of how a city can be redeveloped and protect itself against flood risks through implementation of adaptation measures and smart spatial planning (Nillesen, 2022). Urban developments in Zwolle's inner city located in unembanked area, such as Kraanbolwerk, are therefore inspired by HafenCity (Rijksoverheid, n.d.).

Figure 31: View of HafenCity (Fotofrizz, HafenCity Hamburg GmbH)

In HafenCity, the decision was made not to create an embankment for the terrain in order to preserve the river views and avoid the expenses associated with reinforcing the quay edges. Instead, the central part of the terrain was raised (Nillesen, 2022). As they say themselves (HafenCity, 2023): *'Despite the risk of occasional flooding, HafenCity is neither surrounded by dikes, nor cut off from the water. Instead, with the exception of the quays and promenades, the whole area is being raised to between 8 and 9m above sea level. The concept of building on artificial compacted mounds (warfts) lends an area once dominated by port and industrial uses a new, characteristic topography, retaining access to the water and the typical port atmosphere, while guaranteeing protection from floods.'* Due to implementation of adaptation measures, both physical as non-physical, the area is protected during flood events. Since the development of HafenCity, the last storm surge in 2013 with a water level of 6,09m NN (second highest ever measured in Hamburg), did not cause any casualties or damage.

A second infrastructure, including flexible bridges and floating pontoons, for pedestrians at the level of 7,5m NN (Normalnull, corresponds to NAP), has been realised. This level can also be used for emergency services in case of flooding. Ground floor levels of all buildings are closed up to this height. Openings like doors and windows are all lockable according to special guidelines (Groenblauwe netwerken, n.d.). Certain historic buildings, such as the UNESCO-protected red brick warehouses of Speicherstadt from the 1880s in the district, have been preserved at their original lower level but reinforced to withstand periodic flooding (Yeung, 2021). They have direct access to the upper floors and reinforced windows and other waterproofing measures below. Moreover, the public promenades along the river have been likewise designed in a flood-proof way.

Decision-making process and costs distribution

After the storm surge in 1962 that caused around 300 casualties, the municipality of Hamburg decided not to give permission to build outside the embankment line. This changed in 2000 when the city say the potential of an attractive living environment in the heart of the city closely connected to water, eventually leading to the Masterplan HafenCity (Mees et al., 2013). Building a new dike line around the area of the HafenCity was discussed during the conception of the Masterplan, but for reasons of timeline, investment and urban design efforts, this conception was not pursued (Employee of HafenCity, PowerPoint presentation, 2023). Therefore, it was decided that the high water protection in the HafenCity will be realised by a combination of elevated areas (dwelling mounds) plus protection for the individual properties and buildings as well as additional measures on public areas (Employee of HafenCity, PowerPoint presentation, 2023).

The construction of infrastructure in a city is costly but of crucial importance, as it not only influences the city's current quality but also shapes its future possibilities. Infrastructure in HafenCity, exemplifies this approach by incorporating flood protection measures early on and integrating infrastructure planning with urban development, ensuring sustainable and timed development in line with private construction projects to enhance the city's long-term sustainability (HafenCity, 2023). HafenCity has therefore adopted the 'Warft' – model, a protective mound in marshy areas against rising water. Streets are built at a raised level of 7,5 to 8,0m NN and building are connected to the protected level. Buildings are generally set back from the water's edge, creating approximately 10,5 km of new waterside promenades at the historic level, with flood protection measures for non-residential buildings in the plinths, while the first floor aligns with street sidewalks. High water protection is as follows:

- Design level of protection is +8,3m NN
- In unfavourable zones depending on wind and wave impacts and foreland geometry up to 9,50m NN

Interesting to notice is that the protection level used to be +7,5m NN, but was later on updated to the current +8,3m NN because of new predictions in sea level rise (Mees et al., 2013; employee of HafenCity, PowerPoint presentation, 2023). The protection levels are improved every 10 years. During the interview with a HafenCity employee, it did not become clear how the exact number was determined as they receive the protection levels by the environmental authority. Figure 32 gives an overview of the different heights and infrastructure in HafenCity and give a profile cut for a part of the city.

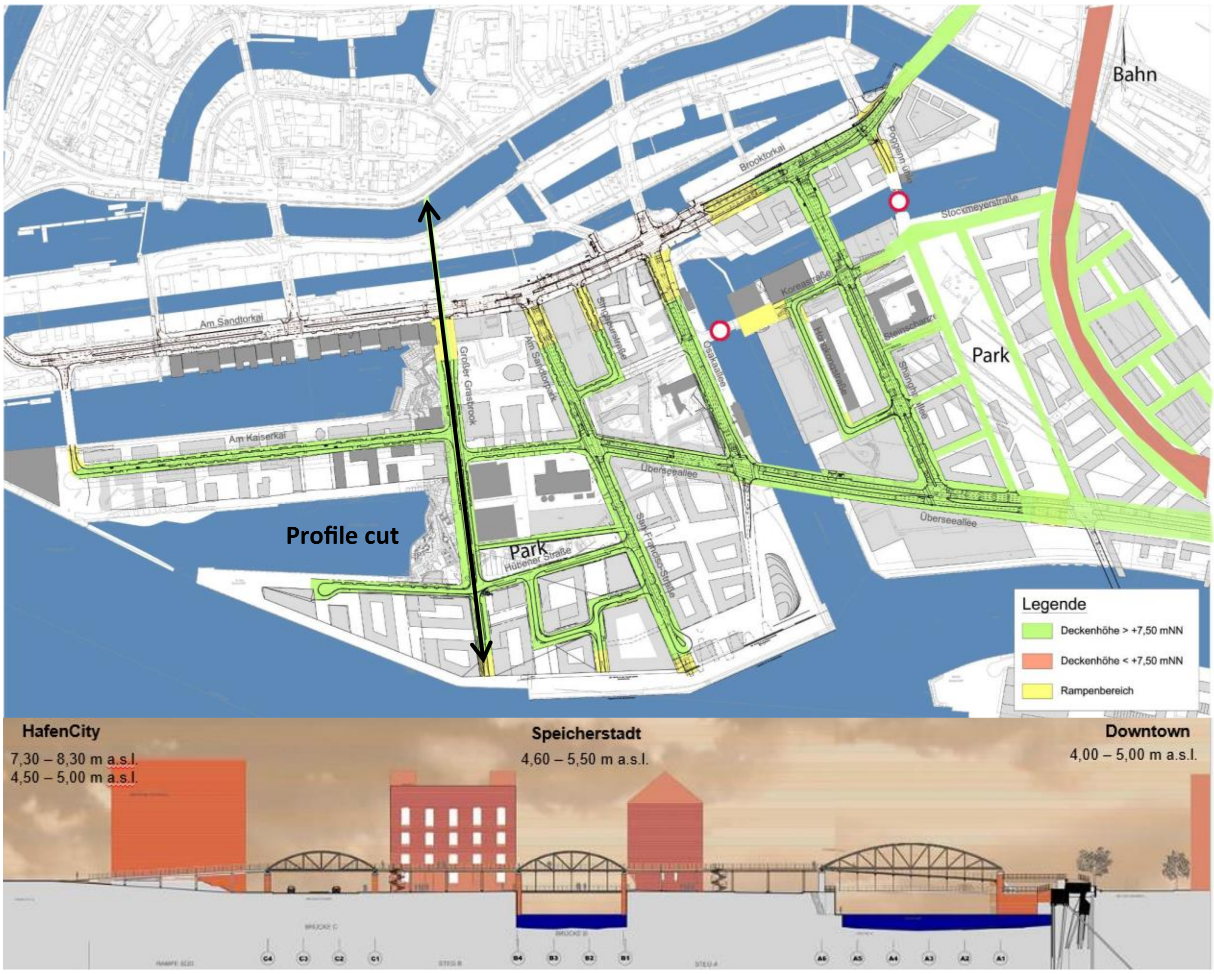

Figure 32: Linking flood protected downtown to raised HafenCity (PowerPoint presentation, HafenCity Hamburg GmbH, 2023)

HafenCity Hamburg GmbH is subsidiary of the municipality and the land owner of the area. It operates as a company and is responsible for designing and constructing the infrastructure, the public areas and the dwelling mounds (Hafencity, 2023). Once the construction is complete, the ground is sold plot-by-plot to private investors and developers. In the end, they are required to finance the elevation of the building plots. This makes it similar to the Netherlands where a municipality has a duty of care for habitability and safety in unembanked areas, but eventually sell ground to investors and developers, thus securing funding for public space and infrastructure.

Decision-making on suitable adaptation measures is done together with the investors and developers. It is an advantage operating as a company and being in direct contact with the other parties. From their experience, it works very advantageously that the entire area development is coordinated and centralized through one company, Hafencity Hamburg GmbH. Once the whole area is completed, the company will be terminated.

In case there are extra requirements, property owners can get a discount in the land price. For example, for the flood walls on the promenade, there is mutual agreement between HafenCity and the developer. In the end, the developer finances the flood walls, but they got a discount in land price of the complexity and risks involved in implementing a new technology.

Since 2006, the HafenCity area has held priority area status, meaning that zoning plans are reviewed by the Commission for Urban Development, comprising representatives from all political parties in Hamburg's City Parliament. Additionally, the Urban Development and Housing Ministry (BSW) takes charge of their development, and building permits are issued by the Ministry instead of the typical district administration (HafenCity, 2023).

Ultimately, the high tide protection in the HafenCity belongs to the property owners, just like in other places where people live in front of the main dike line, and living and working there is at own risk (Employee of HafenCity, PowerPoint presentation, 2023). Material damage caused by a storm surge is not insurable, so property owners have to pay for that themselves. So far, the interviewee is not aware of any discussions around insurance issues. The government only set and controls rules for the area. The municipality of Hamburg set a special of rules for storm surge protection which are related to (Flutschutzveronrdnung HafenCity, 18-06-2002):

- threatened zone
- responsible persons
- creation of communities for storm flood protection
- insertion of a storm flood protection commissioner
- storm flood protection installations
- storm flood protection plan
- storm flood protection practices

Despite all flood control measures, the failure probability of engineering structures must be considered. For example, the 2007 storm surge showed that some flood doors did not close properly, resulting in flooded garages and storage areas (Mees et al., 2013). The interviewee also addresses that it can be problem when the doors in a few years' time do not need closure, technical knowledge is lost or is not transferred to the responsible persons over time.

Finally, two comments that stand out from the interview. First, the link to land and water has been very important throughout the development process. In making decisions for all adaptation measures, the experience of water has been the starting point, and it is believed that people should have the opportunity to connect directly with the water, off course if in a safe way. Second, even though different protection levels have now been used for the construction of HafenCity and are reviewed every 10 year, the interviewee believes that the level will never exceed the height of the adjacent dike. For decades to come, this protection level should provide sufficient protection. Should a severe storm surge with a height higher than the embankment line occur, the consequences will be much more worse than in HafenCity. Therefore, the interviewee does not expect that the protection level will ever exceed the height of dike, as it would then be wiser to focus on better protection of the inner dike area.

4.7. Overview of lessons learned

This chapter explored real-world examples illustrating the decision-making process in developments within unembanked areas. The analysis involved reviewing developments in different cities, encompassing both completed projects and those still in the planning stages. Ultimately, these insights were employed to respond to the sub-question 2*: 'What decision-making methods have been used in recent projects in unembanked areas, and what can be learned from these practical examples?'*

For answering the first part of the sub-question, Table 8 provides a summary of the decision-making tools used in the examined cases.

Table 8: Overview results case studies

Case study	Level of flood risk measure(s)	Decision-makings tools and process
Rotterdam, the Netherlands: Issue level policy	Regional	- Different risks assessment methods over time - Current issue level based on form of CBA that addresses the trade-off between site elevation and flood risks
Rotterdam, the Netherlands: Merwe-Vierhaven (M4H)	Area / building	- Mix of quantitative assessment (form of CBA) and qualitative assessment (time/flexibility, feasibility, effectiveness, and spatial identity)
Vlaardingen, the Netherlands	Area	- MCA incl. spatial quality, technical elements, water safety, management and maintenance and costs
Zwolle, the Netherlands	Area / building	- Principles (*uitgangspunten),* would later be used as criteria for MCA
Copenhagen, Denmark	Regional	- CBA for storm surge barriers
Hamburg, Germany	Area / building	- Principles (*uitgangspunten)* and strict regulation

To arrive at realistic and feasible adaptation measures in unembanked areas, it is essential to consider the existing built environment and local characteristics. For example, elevating an entire area to a specific safety level (e.g. issue level) may not always be feasible or desirable due to constraints imposed by assets such as (critical) infrastructure, trees, and cultural heritage, as well as considerations related to the connection with surrounding areas. Furthermore, allowing water onto the quays during high tides can be a deliberate choice, provided that properties and public spaces are designed accordingly. This approach fosters a new living environments and contributes to the creation of greater water awareness among users and residents in unembanked areas.

The real-world examples highlight that raising sites/buildings or implementing barriers in public spaces is often the most economically efficient solution from a flood risk perspective. However, for unembanked areas, considerations related to the experience and connection with water, along with the preservation of cultural (historical) landscapes and quality of nature, play a crucial role. Therefore, to develop a tailor-made approach in unembanked area development, these factors must be taken into account. From Table 8, it is evident that MCA, grounded in various principles (*uitgangspunten)* translated into criteria such as flood risk reduction, spatial quality, (cost)-effectiveness, and other relevant factors is widely used in unembanked area development to arrive at a set of measures.

5

RISK GOVERNANCE

5.1. Introduction

The societal challenge towards a climate-adaptive living environment requires a process of public and private effort and thus cooperation (Samen Klimaatbestending et al., 2020). Flood risk management is a dynamic decision-making and developmental process involving various stakeholders from different fields at different levels (Schanze et al., 2007). All flood risk measures, no matter big or small, physical or non-physical, have different impacts on stakeholders. It is therefore important to look at how stakeholders are involved in decision-making for measures, but also how they are affected by current or future choices made.

In recent years, local stakeholder involvement in European flood risk management has gained importance due to the increasing complexity of flood risk reduction options (e.g. structural defences, spatial planning, and property-level protection), which exceeds the capacities of governments in terms of expertise and funding for implementation on their own (Begg, 2018). According to Van Asselt and Renn (2011) '*risk governance pertains to the various ways in which many actors, individuals, and institutions, public and private, deal with risks surround by uncertainty, complexity and/or ambiguity*'. Van Asselt and Renn (2011) conclude that one of the ways to define risk governance is '*as the critical study of complex, interacting networks in which choices and decisions are made around risks'.*

Thus, the term risk governance is applicable to decision-making for flood risk measures in unembanked areas. This is particularly interesting as laws and policies for unembanked areas differ from embanked areas in the Dutch legal context. And, as became clear by now, a lot of stakeholders are often not aware of what unembanked areas entail; so are they even conscious of unembanked areas and if so, how do they deal flood risk or how are they involved or impacted by decisions on adaptation measures? Do various stakeholders share a common risk perspective and approach in the decision-making process related to investments in unembanked areas, or do they have conflicting interests?

This chapter will examine how stakeholder involvement affects decision-making for local measures in urban unembanked areas. This is done to get a better understanding of how social costs and benefits are distributed and what social or financial impact certain measures have on stakeholders. Moreover, relevant legislation for unembanked areas is mentioned and ongoing developments in the Netherlands on building climate-adaptive will be explained, as this has effect on the decisions made for implementation of flood risk measures. Describing current developments help to develop policies and interventions that are effective in the contemporary context. Eventually, this chapter contributes to answer sub question 3: *What are the conditions and needs regarding the decision-making process of local flood risk measures in unembanked areas from the perspective of various stakeholders?*

5.2. Stakeholders

There are many parties socially and financially involved and/or affected in flood protection in area development in unembanked areas. Figures 33 and 34 provide, although specifically based on Rijnmond-Drechtsteden, good overviews of involved stakeholders and opportunities to increase flood protection in urban unembanked areas. Based on these Figures, Nationaal Deltaprogramma Rijnmond-Drechtsteden (2022), Van Den Dool and Valkenburg (2022) and interactions with experts, the following stakeholder groups have been identified as most important when considering social and financial involvement and impact in local adaptation measures in area development in unembanked areas:

- National government
- Province
- Municipality
- Waterboards
- Rijkswaterstaat
- Safety region
- Utility companies
- Companies
- Citizens
- Housing corporations and property owners
- Developers
- Financial institutions

Figure 33: Overview parties with interest and responsibilities in unembanked areas (DPRA = Deltaprogramma Ruimtelijke Adaptatie, RO = Ruimtelijke Ontwikkeling, V&K = Vitaal & Kwetsbaar, Brzo = Besluit) (Gebraad et al., 2018).

Stakeholder groups

- Municipality (public space)
- Delta Programme Rijnmond Drechtsteden
- Rijkswaterstaat
- Water boards
- Social housing corporations and property owners outside the dikes
- Port of Rotterdam
- Safety region
- Utility companies

Linking opportunities

- New housing in unembanked area, such as M4H, Waalhaven
- Environmental vision for densification unembanked areas in city centre
- City centre and Zuid restructuring and large-scale renovation
- NPRZ
- Planned renovation and maintenance of existing buildings
- Tidal park XL Programme

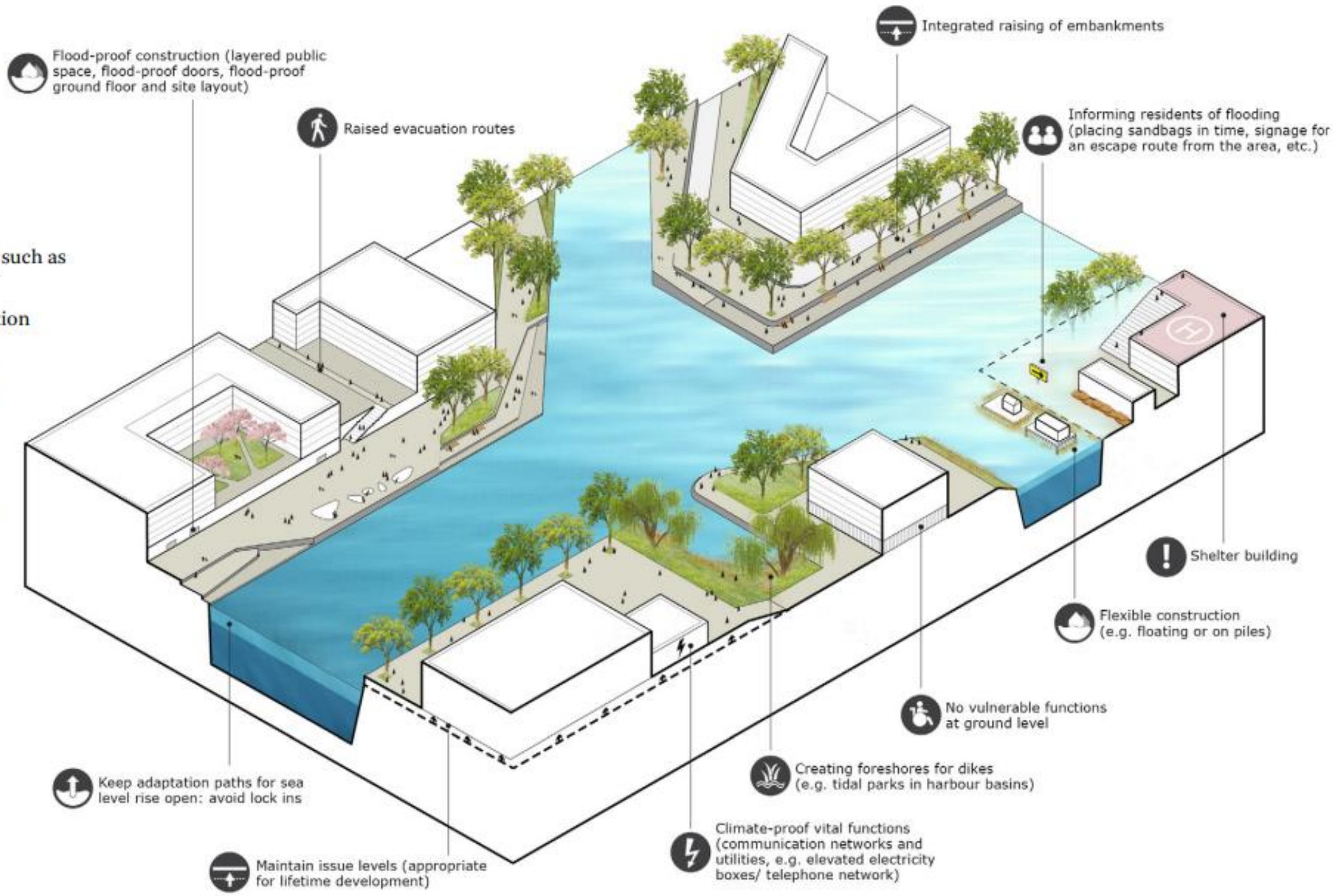

Figure 34: Opportunities to increase flood protection for unembanked areas including stakeholders groups (Rotterdams WeerWoord, 2023)

For industrial areas in the region Rijnmond-Drechtsteden, the Port of Rotterdam and DCMR Milieudienst Rijnmond are important as well. For instance, the Port of Rotterdam retains port activities in M4H and is partly landowner there. Apart from this, these actors will not be further discussed in this Chapter. Moreover, although nature organisations are named, they are excluded in this research as they are mainly important for unembanked areas in rural regions.

For companies, it is important to recognise a distinction between utility companies and other (commercial) companies. While both own assets in unembanked areas, utility companies like electricity and (drinking) water companies provide vital and vulnerable infrastructures where disruption has a greater impact on society than damages on other companies.

Although citizens may also fall into the category of property owners, it is good to name citizens as a separate stakeholder group as well. After all, it is good to consider flood risks and measures in unembanked areas from a broader social perspective. To consider social impacts such as equity, inclusion and justice in climate adaptation decision-making, it is important to include citizens as a distinct group (Chu & Cannon, 2021). Besides citizens who own property, there are also citizens who work and recreate in unembanked areas. Take the example of HafenCity, where waterfront promenades are a tourist attraction and area development thus has greater social value on all citizens.

Developers need to consider climate adaptation measures in several ways. They drive the development of buildings and areas for the market. Developers invest and develop on their own land or obtain a development position through a tender. As more and more regulations are added to build climate-adaptive, the cost of building is increasing. On the other hand, urban unembanked areas offer opportunities given their favourable location near the city and waterfront. Therefore, developers indicate that they would still like to develop in such places.

Financial institutions are added as well. At the moment, it is not possible in unembanked areas for home-owners to get insurance against floods from sea or river, but is interesting to know how they look at climate-adaptive measures and to learn more about developments for insurance possibilities in unembanked areas. In addition, it is interesting to see how banks as mortgage lenders and project financiers are involved in urban unembanked developments. Climate change exposes financial institutions to two types of risk: physical and transition risks. Physical risk is damage and loss due to extreme weather conditions and transition risks relate to loss or (in)direct damage in transition to sustainable and eco-friendly economy to reduce global warming. Financial institutions pose the biggest threat by physical risk in area development in unembanked areas.

Legal responsibilities in unembanked areas

Within Dutch legislation, different rules and responsibilities apply to unembanked areas compared to area protected by dikes. Therefore, the responsibilities are briefly explained here.

National government

The national government sets the frameworks at the national level based on its responsibility for managing the main water system.

Province

Provinces are free to flesh out additional policies for developments in unembanked areas, if they feel the need to. Provinces take flood risks in its spatial considerations, but each province has its own interpretation of its role in unembanked areas, as flood characteristics and land use differ per province. Some provinces set their own spatial frameworks, while other leave it to municipalities or water boards.

Municipality

The municipality is responsible for communicating about the risks in unembanked areas and taking safety measures in case of flooding. Municipalities consider the risks in plans for new developments in unembanked areas outside the dikes, based on their responsibility for good spatial planning. If necessary, they set preconditions to manage these risks. The zoning plans can set requirements for the development of areas outside the dikes to limit the impact of high water.

Water boards

In principle, water boards have no statutory duties for water safety in unembanked areas. However, developments in unembanked areas can have consequences for water quality, quantity and the management of flood defences. Water boards are nevertheless involved in developments via the '*Watertoets'* and emergency plans.

Rijkswaterstaat

Rijkswaterstaat regulates activities in the unembanked areas. It does so by granting permits for and supervising third-party activities on or near the major rivers, with enforcement for regulations accompanying granted permits and general rules applicable there. The assessment framework for granting permits can be found in the *Beleidslijn Grote Rivieren.* It also states which unembanked areas are excluded from applying for a permit.

Safety region

The security regions make an analysis and inventory in the regional risk profile of the most important risks, flood risk being one of them in unembanked areas. Based on the risk profile, the safety region draws up a policy plan, a crisis plan and disaster management plan.

Property owners and users

Residents and users e.g. (utility) companies are responsible for taking consequential mitigation measures and bear the risk themselves for water damage.

Current policies and developments on Dutch sector for building climate-adaptive

At several levels, developments are going on and policies are being made on how to deal with climate-adaptive building. This section will therefore explain as briefly as possible the main developments at the different levels. As this report is written partially for the municipality of Rotterdam, and considering that the majority of users of unembanked areas in the Netherlands are located in the Rijnmond-Drechtsteden region, the focus of this part is directed towards these areas.

National level

At the national level, flood protection and climate change impacts are being considered through the Delta Programme (*NL: Deltaprogramma*). One of the three themes that is focused on is Spatial Adaptation (*NL: Ruimtelijke adaptatie*). The core of this is that the Netherlands will be water-robust and climate-proof by 2050. To implement this, for example, the *Impulsregeling Klimaatadapatie* has been in force since January 2021 and support is provided via *Kennisportal Klimaatadaptatie* and *Klimaateffectatlas* (Ministerie van Infrastructuur en Waterstaat, 2023).

In addition, there is the National Strategy on Spatial Planning and the Environment (*NL: Nationale Omgevingsvisie - NOVI*). Relevant to this study, the NOVI describes that (re)developments should avoid increasing the risk of damage and fatalities from flooding or extreme weather, as far as is reasonably feasible.

However, the problem with the NOVI is that it does not address water safety in unembanked areas (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2020). Moreover, the new Spatial Planning and Environment Act (*NL: Omgevingswet*) is expected at the 1st of January 2024. This will replace the old Water Act.

Moreover, there is a concern around a recent change in the Building Code *(NL: Bouwbesluit*) that specifically hinders climate-adaptive building in unembanked areas. For newly built houses, the requirement of a maximum of 20 millimetres will apply to all entrances to a house. This applies to the route from the public road to the house. Until now, only one accessible access was required. This widened requirement came into force on 1 January 2022. As a result, some flood risk measures such as raised entrances to buildings are not possible, while these may be desirable solutions in unembanked area. So in view of climate adaptation and water safety, this change in the Building Code is undesirable.

Another thing to consider when building in areas close to the dikes is the need to reserve extra space for dike reinforcements. Next year, the Sea Level Rise Knowledge Programme (*NL: Kennisprogramma Zeespiegelstijging)* will present a calculation of the extra space needed along the primary flood defences. The report by Sweco, Defacto, Deltares and Ecorys shows that spatial planners and water managers should at least take into account an extra reservation of 20 to 50 meters for future dike reinforcements (Ministerie van Infrastructuur en Waterstaat, 2021).

In addition, a national 'yardstick' for green and climate-adaptive built environment is created (*NL: Maatlat groene klimaatadaptieve gebouwde omgeving*). This should clarify what climate-adaptive building and design can look like. The 'yardstick' provides national definitions of what climate-adaptive building is. It creates clarity for co-authorities and for building and development parties. The 'yardstick' does not prescribe any specific measures. This leaves room for local customization and allows for innovative and smart solutions. It describes regulations in the form of watertight building, protection against incoming water and flood-proof building. It expressly appointed that the built environment will be prepared for flooding in unembanked areas through consequence mitigation (Arcadis & TAUW, 2022).

Moreover, the national government is financially involved in area developments through subsidies such as the *Woningbouwimpuls*. This has been used both for area developments in Vlaardingen and M4H.

Level of province

At this level, the provincial environmental vision (2021) states that municipalities must make their own assessment for flood risks in the unembanked areas in the case of spatial developments. In addition, the province of South Holland has included an instruction rule in the environmental regulation for climate adaptation. Article 6.50 states that a zoning plan must take into account the consequences of climate change, such as flooding.

As part of the national Delta Programme, a strategy has been drawn up for Rijnmond-Drechtsteden, the area under which Rotterdam falls, in the Deltapromma Rijnmond-Drechtsteden. The preferential strategy is primarily about water safety, but there is also a lot of focus on spatial adaptation and multi-layer safety. All investments in the spatial domain take into account long-term water safety tasking. Area developments take place for the long term and an efficient connection with the water safety task is cost-effective (Deltaprogramma Rijnmond-Drechtsteden, 2020). For spatial adaptation, the Climate Adaptive Building Covenant serves as a guideline. This includes flood requirements that focus on making an area effectively robust in different scenarios with flood depths. The municipality of Rotterdam has also signed this covenant (*Convenant Klimaatadaptief Bouwen in Zuid-Holland*, 2018)

The Covenant on Building Adaptive South Holland *(NL: Convenant Bouw Adaptief Zuid-*Holland) is an example of how to develop new design principles and standards for climate-adaptive building. It was signed in 2018 by various parties such as construction companies, municipalities, province, water boards, civil society organisations, financiers and project developers. The Guide to Climate-adaptive Construction 2.0 (*NL: Leidraad Klimaatadaptief Bouwen 2.0*) that followed in 2022 indicates that an important question is how to deal with the costs and financing of area development and new construction across all phases of spatial developments. The report is created to serve as a guideline for all public authorities and market players playing a role in climate-adaptive development, design and construction (Van Den Dool & Valkenburg, 2022). It is a tool for governments and project developers to quickly determine which resources can be used to build climate-adaptively, thus shaping, for example, consequence mitigation of flooding (Van Den Dool & Valkenburg, 2022). Moreover, Samen Klimaatbestendig, together with TAUW and &Flux, has made an overview of 25 products, guidelines, tools and instruments in the field of climate-proof construction and area development, called '*RITSEN: a guide with climate adaptive tools for building & development'* (Samen Klimaatbestending et al., 2020). The earlier designed Roadmap Climate-Resilient Area Development (*NL: Roadmap Klimaatrobuuste Gebiedsontwikkeling*) is a part of this guide (City Deal Klimaatadaptatie et al., 2019).

Finally, SWECO has developed a no-regret tool for investing in water safety in the event of sea level rise in Rijnmond-Drechtsteden. This should help planners, developers, municipalities, water boards and investors make choices about investments and measures to limit disinvestment early in their plan development (Booister, Sulkers, et al., 2021). For example, when developing a new residential area, one can fill in the publicly available Microsoft Excel tool to get an estimate of the effect of sea level rise in a specific area during the lifetime of the investment. It is also possible to try out and compare different options, such as raising the site, alternative construction methods or placing power sockets at height.

Level of municipality

Finally, for Rotterdam specific, the municipality has to deal with three water boards: Hoogheemraadschap van Delfland, Hoogheemraadschap van Schieland en de Krimpenerwaard en waterschap Hollandse Delta. Each water board has the possibility to define different zones, including a prohibition regime for construction (Internal document Rotterdam, *Factsheet bouwen buitendijks,* 2023). Since there are three water boards, this creates a complicated set of rules in Rotterdam. Because of this complexity, but also because of the lack of space in the city, it is important to approach the water boards and discuss the possibilities as early as possible in the planning process.

5.3. Results from interviews

To gain a better understanding of how stakeholders are involved in and affected by climate-adaptive construction in unembanked areas, multiple interviews were conducted. The objective of these interviews was to explore stakeholders' perspectives on unembanked area development and their involvement in adaptation measures in such areas. Additionally, the aim was to identify any specific requirements or challenges they face in enhancing decision-making processes related to climate-adaptive measures.

The interview format was semi-structured and allowed room for interviewees to discuss their challenges and needs. The interviews commenced with introductions, followed by discussions on unembanked areas and how their organizations perceive these areas and associated risks. Subsequently, the focus shifted to climate adaptation within the built environment. The primary aim was to concentrate on unembanked areas; however, as the interviews revealed, climate adaptation in the built environment as a whole is quite new. Therefore, the discussions covered a broader context. The interview findings are categorized to consolidate prevalent and common topics.

- ➔ **Developing stage: a growing focus on climate adaptation and risk**

Firstly, working on climate adaptation in the built environment is relatively new. All interviewees mention that they have been engaged for a few years in how to adapt to climate change and its associated risks, but that a lot is still in a developing phase.

VRR, for instance, states that they have been dealing with water safety from a crisis management perspective for a while, but this focus was primarily on post-impact response. Working proactively on climate adaptation upfront is relatively new, and they have been actively working on this topic for just a year. Concerning unembanked areas, in the past VRR had not given them significant attention for an extended period since it was assumed that the water boards had already factored in the risks people faced there. However, there is now an increased emphasis on proactive climate adaptation, especially with regard to evacuation and the accessibility of emergency services. According to the interviewee, the VRR should have started this process way earlier. Currently, much time is dedicated to understanding the municipality's needs, their priorities, and their perspective on developments in unembanked areas.

The financial sector is also in the developmental phase when it comes to assessing the impact of climate change and its consequences on their portfolios. It is noted that the financial sector is still evolving in response to these changes. In the past, there was heavy reliance on the Delta Works and other preventive measures, but due to climate change, more consideration is now given to the impact and safety consequences. Efforts are being made to figure out how to address this, including practical aspects such as handling financing requests in areas where risks might be deemed too high. For instance, in one of the interviews, it was indicated that financial institutions are gaining better insights into which impacts can be mitigated through climate-adaptive measures and discussions are emerging regarding insurability of certain risks and its implications for financing. This was confirmed in another interview with a financial institution, which also mentioned that they are increasingly focused on assessing the consequences of climate change, their own role and the possibilities of climate-adaptive measures.

Moreover, it is noted that in Europe, with the recent events in Limburg and Germany, floods are receiving increasing attention and that despite the high safety standards, there is a growing awareness that preventive measures like a dike might fail. All in all, it is all quite new, and the stakeholders are working on how to deal with climate-adaptive construction.

➔ **Unawareness of unembanked areas and risk perception**

During the interviews, and also in other interactions with experts and stakeholders, it is indicated that there is still a poor awareness of the existence of unembanked areas and what this exactly entails. Everyone can give an example of a colleague or a manager who is not aware of unembanked area, where they are and what risks are involved, even though this person lives in an unembanked areas or has to deal with this in work.

A lack of understanding of unembanked areas therefore leads to misplaced or incorrect risk perceptions. For example, many people state a priori that they are against building in unembanked areas, without being aware of the locations and the flood risks in that area. To illustrate this, an interviewee described a situation where, during a working visit to the Rijnhaven, a board member indicated that he was against building in unembanked areas, not realising their company was recently involved in area development here and was not aware that this was unembanked area.

Anecdotes like this were given through the whole research process,. Another example is during the field visit in Zwolle, it was indicated that board members or aldermen are not aware of the unembanked areas or the kind of area development that is going on there. It is important to note that this obviously varies from person to person, but it does indicate that there is still poor awareness and risk perception of unembanked areas.

The very fact that something is called 'unembanked' gives the impression that properties are not protected at all against flood risk or at larger risk for damages, while measure like dry- or wetproof building or amphibious construction prove that properties can be protected against flood risk in an effectively manner, ensuring a comparable safety level as the inner dike areas. This is issue is also mentioned in a conversation with an insurer who explained that in general risk in unembanked areas are seen as higher since they experience that the conversation is more on protected and unprotected areas. This is part of the reason why it is not possible to get an insurance in the unembanked areas, and it can be argued that the risk perception of flood risk in unembanked areas, labelling them as unprotected, is problematic.

Moreover, VRR also indicate that difference of awareness within municipalities. In its advising role to municipalities, VRR emphasises when municipality are planning to operate in unembanked areas. Large municipalities such as Rotterdam are already much more aware of this, but VRR notes that smaller municipalities such as Voorne aan Zee are not always aware when planning new area developments in unembanked areas.

➔ **Living with water**

Relevant to the awareness of flood risks in unembanked areas, the theme of 'living with water' aligns well. Within the municipality of Rotterdam, as evident in M4H's adaptation strategy, the concept of 'living with water' holds significant importance. It involves considering how water can be integrated into public spaces and preparing areas for potential flooding. It aims to allow water into the area during high water levels without causing damage.

Both the municipality and developers provide examples of tidal parks designed to raise awareness of water within the region. During several interviews and stakeholder interactions, the need for a mindset shift towards accepting water on land during high tides, giving the area is designed accordingly, is emphasized. Case studies from other cities like HafenCity align with this concept, demonstrating that the experience of water and its natural movements becoming more important in public spaces in unembanked areas, as long as this can be done safely and responsibly.

➔ **Opportunity's in unembanked areas**

Heijmans expresses a proactive approach, viewing construction in urban areas directly by the water as a unique opportunity. The municipality also observes significant interest from developing parties in constructing on such distinctive locations.

Furthermore, there is sufficient room for housing, and developers consider this an opportunity for area development. This naturally comes with investment risks, but, at present, interviewees state there is no indication that this makes developing parties more cautious.

➔ **Move from distinction between 'embanked' and 'unembanked': let's talk about risks**

While interviewing financial institutions, it is notable that rather than discussing whether areas are inside or outside dikes, the focus shifts towards examining the risk profiles of an area. Banks emphasize that, at present, there is no practical differentiation between their policies, investments, and portfolios concerning areas inside or outside dikes. Therefore, whether a asset legally speaking falls within 'embanked' or 'unembanked' areas is of less concern for them. However, the risks involved are way more interesting and of importance. Thus, gaining insights into the climate risks in these unembanked areas has more values for them.

Considerable knowledge is still being gathered on climate risks and their impact on portfolios and investments. However, excluding certain locations from investment is currently not a significant consideration and remains a decision for each financial institution to make independently. Risk managers assess risks on a case-by-case basis for each situation and investment. Still, there is not yet a concrete industry-wide policy on how to address the risks of building near rivers.

Insurers also primarily approach this matter from a risk perspective when making their decisions. While insurers are together working the national government on making flood risks from the sea or rivers insurable, they find it more crucial and intriguing to focus on risk profiles rather than the legal distinction between 'embanked' and 'unembanked' areas. This is because the current assumption is that risks in unembanked areas will inherently be higher, which is a flawed presumption. As demonstrated, with appropriate measures, it is possible to safely live in and utilize unembanked areas. However, except for a few exceptions for companies, property owners in unembanked areas are excluded from insurance coverage.

➔ **Unclarity in responsibilities**

During the interviews and discussions with the involved parties, it is repeatedly emphasized that it sometimes remains unclear who bears what responsibilities in the unembanked areas. For instance, in the interview with Rijkswaterstaat and during the field visit in Zwolle, it is mentioned that many people still distance themselves from unembanked area development, often leaving it to the municipality's sole responsibility to address this issue. The interview with VRR also highlights the challenge of responsibilities for water safety frequently falling on different parties.

It is also evident from other interviews and expert interactions that it is unclear who bears what responsibility when implementing climate-adaptive measures. For example, where does the municipality's duty of care for a safe and proper spatial planning end? In the example of Vlaardingen's decision to place a physical barrier to protect private properties, the question arises whether responsibility for flood risks shifts to the municipality as the owner and manager of the quay wall, or if it remains with the residents living in unembanked areas. Such a measure could create a false sense of security, as in theory, citizens and users would still be responsible for water damage to their properties.

➔ Need for clear definitions, guidelines and frameworks

The '*Kamerbrief voor Water en bodem sturend'* does have a significant impact on the water and sector and spatial developments. However, multiple stakeholders have expressed that it is unclear what are precisely the consequences of the content of the letter, leading them to interpret the letter in their own ways.

For instance, the letter states that in certain areas, building in the floodplains outside the dikes is no longer allowed. Yet, there is uncertainty among stakeholders about the exact definitions and distinctions between "buitendijks" (unembanked) and "uiterwaarden" (floodplains). This issue is also raised in the interview with an insurer, emphasizing the need for a clearer distinction between "buitendijks" and "uiterwaarden." "Uiterwaarden" are also situated outside the dikes and primarily intended to give rivers more room. These areas are more prone to flooding then urban unembanked areas and therefore less suitable for area development, giving their lower elevation level, but where should the line be drawn? It is suggested that when defining "buitendijkse" areas and "uiterwaarden," the focus should be more on the risks and potential damages. This approach would help determine which areas are suitable for future developments.

The same problem occurs when looking at 'vital' and 'vulnerable' infrastructure. There is a need for better definitions as each party makes its own assessments and decisions of what falls into these categories and creates its own definitions.

For climate-adaptive construction, financial institutions, developers, and VRR, among others, express the need for clear standards and definitions of what precisely constitutes on climate-adaptive building. They seek guidelines on what is permissible and mandatory. Different interpretations exist regarding what climate-adaptive construction entails, and therefore, there is a desire for generic guidelines to be established.

Specifically for unembanked areas, it is indicated that setting safety standards is desirable. What risks are acceptable, and which ones are not? In an interview with a financial institution it is also suggests that establishing requirements and standards for climate adaptation in unembanked areas is beneficial for assessing insurability. Standardizing rules is therefore desirable.

In two interviews, the suggestion is made that efforts could be directed towards creating a minimum set of measures to meet climate-adaptive construction requirements. In addition to a minimum safety level provided, parties would still have the freedom and flexibility to set further requirements, but at least there should be a baseline.

➔ Equal playing field through legal obligations

In addition to the '*Kamerbrief Water en bodem sturend*', many parties are involved in the national building standard. The issue raised here is that this standard is not legally mandatory. Its application is voluntary and currently only applies to new construction. Financial institutions emphasize the desirability of making it compulsory to specify the building requirements for something to be considered climate-adaptive construction. By making this a legal requirement, applicable in the future also to the existing built environment, it provides clarity for all parties and creates a level playing field.

In the realm of climate adaptation measures and factoring in climate risks, it is suggested that taking the first step can put a company at a competitive disadvantage. It also requires courage to take on a pioneering role, and financial institutions are therefore hesitant to be the first to act. This is why banks are currently cautious about quantifying climate risks. They do not want to expose themselves to a competitive disadvantage due to the sensitivity of the matter and their own position. Making it a legal requirement and establishing better laws and regulations in this regard is helpful. The sense of urgency and the necessity become more apparent when it becomes mandatory, similar to the introduction of the energy label a few years ago. It is also highlighted that regulation is a convenient way to involve the entire insurance market in climate adaptation instead of only a few insurance companies trying to insure flood risks.

➔ **Legal binding and enforceability**

Additionally, it remains challenging to legally enforce certain matters. For example, VRR acts as an advisory partner, but the ultimate decision lies with the municipality on how to proceed. VRR cannot impose anything. For instance, they recommend against locating vulnerable facilities such as schools or hospitals, i.e., places where people are less self-reliant, in unembanked areas. However, in the Masterplan of M4H, it is later mentioned that an elementary school will still be established in this area.

The issue of legal enforcement is also recognized in the case of the issue level policy in Rotterdam. Moreover, during the Vlaardingen case study, it was noted that it is difficult to legally compel users and property owner to share in the costs of the physical flood barrier, as this is part of the public space and the municipality is not selling ground to developers.

The interviews and stakeholders interactions show that the "how" and "where" of construction are becoming increasingly important. There are strong calls for more regulation and legal obligations to ensure not only better definitions, guidelines and frameworks, but also legally binding agreements. As an example, it is repeatedly mentioned in interviews that the '*nationale maatlat voor groene klimaatadaptieve gebouwde omgeving'* is currently voluntary in nature, but stakeholders would benefit from more legal obligations attached to it. This aligns with one of the recommendations by Harbers (2022) to legally safeguard the *'nationale maatlat'*.

➔ **Leading role of government in creating awareness of climate risks**

Several interviews highlight the logical role for the (national) government to take the lead. This is important for various reasons, as previously mentioned, such as establishing clear guidelines, frameworks, definitions, and legislation to ensure an equal playing. However, the (national) government also plays a significant role in communicating climate risks to citizens.

Financial institutions see a logical role for the government in communicating awareness of climate risks to citizens. In one interview, a scenario is outlined in which it could lead to uncomfortable discussions between citizens and financial institutions if they are the ones informing citizens about certain climate risks. From the perspective of financial entities, it makes more sense for the government to take the lead in informing citizens and businesses about climate risks, rather than them being the messengers. This relates to the duty to inform and communicate about risks. If specific databases or maps indicate an elevated risk in an area, it would be logical for this information to be disseminated by the government and not solely through a bank or insurer.

➔ **Determining risk: on what information, maps and databases?**

In the interviews, several organizations share common practices and challenges related to the use of data and mapping risks. Many of them use the *Klimaatatlas* as source, but many parties also have their own databases. Multiple stakeholders emphasize the need for localized risk assessments, using postcode-level data for more accurate decision-making. However, there is a discussion about the standardization of data and maps.

In addition, in one of the interviews it is pointed out that keeping databases and maps up to date is challenging. An example is given in which a certain area is labelled with a potential high climate risk based on the data input of the system, while it is known in reality that there are already measures being implemented to reduce that climate risk. Therefore, assessing and determining climate risks is made more difficult since the maps and data contradict reality.

Finally, the Red&Blue symposium featured a presentation highlighting the overwhelming abundance of guidelines, frameworks, maps, and information services, both public and private. This multitude sometimes leads to contradictions, creating challenges in determining which sources to consult for which purposes. The presentation underscored the difficulty in adding reliable labels to homes, as this requires very accurate local information and expertise. For instance, it was demonstrated that incorporating all data into risk assessments for labelling poses challenges. It was emphasized that assigning a risk label to homes could be problematic when giving without an action perspective for the asset user, especially when necessary measures fall beyond the boundaries of the property, such as adapting sewer systems to handle extreme rainfall. While it is highly complex to assign a reliable flood risk label to a property, various financial institutions mentioned in the interviews that, for communication and determining the values of an asset, it would be beneficial to use a universal risk label, similar to the energy label introduced several years ago.

- ➔ **Demand for wider partnerships**

Throughout all the interviews, as well as in many other interactions with experts and stakeholders, the need for greater collaboration between parties is emphasized. VRR, for instance, mentions that agreements are often made per municipality at present, but there could actually be broader collaboration involving multiple parties to enhance water safety. They point out that water doesn't adhere to municipal boundaries, so it would be beneficial to have discussions on a larger scale. The national government could also play a role in this. VRR also suggests that, in the case of unembanked areas, this would help in terms of creating awareness of ongoing developments. Some parties may have less involvement with unembanked areas, but by discussing these issues at the same table, all parties would be informed.

Financial institutions also express a need for broader collaboration. If all insurers were to work together, it would be easier to insure against climate risks and it prevents depending on one or two parties having to take the lead. The same applies to banks, which in addition indicate that there is also more room for collaborations between public and private companies.

Many parties are currently working on the same topics. It is suggested, for example, to work more with open-source approaches between both public and private parties, so that knowledge can be exchanged more easily.

- ➔ **Non-insurability in unembanked areas as discouragement**

Not insuring properties in unembanked areas is partly used to discourage construction in these areas, as was addresses during the interview with a financial institution. It was said that it not just a matter of whether it's possible to offer insurance, but it is seen as a way to discourage further construction in unembanked areas. In the debate about whether or not to develop in unembanked areas, the idea is that it should not incentivize construction in these areas if by making it insurable. By this, it is meant that it is not encouraged from insurers to build in places of increased flood risk, and making water damage in unembanked areas non-insurable is an option to discourage this.

➔ **Social justice in climate adaptation**

The financing of climate adaptation measures is in area development in unembanked areas is ultimately borne by the future buyers. For example, this can happen through increased construction costs or land development expenses, and developers will pass these costs on to future customers. For unembanked areas, it raises the question of fairness when individuals have to bear additional expenses to ensure safety in their residential areas and invest in climate adaptation measures, yet they cannot obtain insurance.

Also, the planning economist of the municipality points out the social justice aspect, wondering whether people consciously choose to live in unembanked areas, considering that they might have limited housing options in other areas and it is the municipalities choice to develop this areas. In an interview with a bank the complex issue of who pays for climate adaptation through public-private collaboration was addressed. They also discuss how factors like overvaluing houses could inadvertently push more vulnerable communities into riskier areas, creating social justice concerns.

Furthermore, in one of the interviews with a bank, the role of postcodes was highlighted in this context and the associated challenge of not being able to discriminate based on them. This creates a tension as climate risks are closely tied to a specific location. While differentiation based on postcodes is accepted in areas such as car insurance, it is not possible for mortgages due to the principle that everyone should have the right to housing, maintaining an element of fairness. Just to make sure, it was not stated in this conversation that the bank would like to take action on this matter, but there was a question about how to handle with this information from a social perspective as it is known that certain locations face greater risk, yet there is not much in practice a bank can do about it yet.

➔ **Use of principles**

During the discussion with the project manager of M4H, it was mentioned that, in the area development, working with certain principles is common practice. For instance, in M4H, it was established that specific cultural-historic buildings needed preservation. Starting from this principle, the focus shifted to determining the best way to protect these buildings from flood risks. In such cases, the emphasis is on efficiently exploring the most cost-effective methods for protection, making a full cost-benefit analysis unnecessary.

6

CONCLUSION

Cities worldwide are already impacted by climate hazards like heavy precipitation, heat stress, flooding, drought, which are projected to worsen due to climate change. Unless measures are taken, the probability of flooding will increase due to sea-level rise, higher river peak discharges, and land subsidence. Areas not protected by dikes, known as unembanked areas (*NL: buitendijkse gebieden*) are particularly vulnerable due to their direct location to the sea or river. However, pushed by urbanization and the housing crisis, and the perceived attractiveness of the higher elevated locations on the waterfront; there are many plans for area (re)developments in unembanked areas in the Netherlands. To effectively address the impacts of climate change and avoid passing on the consequences to future generations, the implementation of adaptation measures is essential for developments in unembanked areas.

These measures can be taken at different levels (e.g., regional, local or building), and the location characteristics call for a tailor-made approach. The fact that many parties are involved or affected in flood risk management and spatial planning, the dependency on decisions taken at different (governmental) levels, and uncertainties in the rate and magnitude of climate change complicates the question on how to deal with flood risks on a local level in unembanked area development. Adding to this complexity, unembanked areas have no standard safety levels as they are excluded from the Dutch Water Act and responsibilities and duties differ from the embanked areas. This is compounded by the fact that many stakeholders have a false, low or non-existing safety perception or risk awareness in unembanked areas, if they are even at all aware of what unembanked areas are.

Determining the set of flood risk measures fitting for a specific location in the unembanked areas is thus a very complex and multifaceted task. The objective of this research is to gain a better understanding of the decision-making process for local flood risk measures in area development in unembanked areas. There is a need for a transparent evaluation method of potential flood risk measures to support decision-making in spatial planning and flood risk management in the unembanked areas. This study aims to contribute to this by examining various evaluation methods and how they are used in the decision-making process in unembanked areas (both from theory and practice). Furthermore, stakeholders' needs and challenges in the decision-making process for climate-adaptive measures relevant to unembanked area development are examined.

SQ1: What evaluation methods are commonly used in flood risk management, and how do these various evaluation methods facilitate the decision-making process in area development in unembanked areas?

Before delving into the evaluation method, it should be noted that multiple studies indicate that the multi-level safety (MLS) concept, however originally designed for areas within the dike rings, is also highly suitable for unembanked areas. Investing in layer 2 (damage reduction through spatial interventions) and layer 3 (crisis management) is more complex due to the involvement of more parties than focusing solely on layer 1 (preventive measures). Nevertheless, it is very rewarding in unembanked areas to invest in the other layers as well. Moreover, the proposal to expand the MLS concept with additional layers for recovery and water awareness aligns well with the challenges faced in unembanked areas. While the MLS approach does not function as an assessment method, it is essential to highlight its appropriateness as a framework for organizing potential measures. The approach can effectively serve as a conceptual guide for adaptation measures in unembanked areas, thus contributing to the decision-making process.

Moreover, frameworks such as adaptive pathways (AP), adaptive tipping points (ATP), and adaptive delta management (ADM) have been used for adaptation strategies in unembanked areas. These resilience-based planning methods offer valuable guidance in the decision-making process and serve as an effective means to facilitate ongoing decision processes by assisting decision-makers in choosing future adaptation options that align with changing environmental and societal conditions. For unembanked areas, these approaches were found to be effective methods to evaluate and select appropriate urban flood adaptation strategies. Instruments like (social) cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), or multi-criteria analysis (MCA), when applied thoughtfully within the framework of adaptive pathways, can contribute to risk-informed decision-making and the development of flexible strategies that can be adjusted over time based on evolving conditions and knowledge.

Now, on evaluation methods, social cost-benefit analysis is a widely used tool in flood risk management and spatial planning. This tool serves as an objective means to evaluate policy alternatives or measures, quantifying their effects, uncertainties, costs, and benefits in monetary terms for as much as possible. Different types of CBA (as how the term is abbreviated in the *General Guidance for Cost-Benefit Analysis (ENG) / Algemene Leidraad voor Maatschappelijke Kosten-Batenanalyse (NL)*) do exist, such as a complete CBA (incorporating all social costs and benefits and monetizing them as much as possible) and lighter versions like key figure or quick-scan CBAs. Other evaluation methods, including cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), and impact assessment (IA), are also commonly used evaluation methods in flood risk management.

Literature emphasizes the importance of considering non-monetary or intangible effects, like impacts on nature, landscape, historical heritage, and stress from flooding, in CBAs. Nevertheless, there are limitations to the usefulness of CBA in the decision-making process. If the key effects cannot be accurately measured or monetized, a CBA can only provide incomplete information with restricted reliability and relevance. Despite ongoing attempts, quantifying and monetizing social impacts such as spatial quality remain challenging due to a lack of adequate valuation methods. Moreover, there are no key figures for this matter that could be used for a lighter version of CBA. Yet, studies show that incorporating these intangible effects can provide more robust decision-making on adaptation measures at the local or building level for stakeholders in flood risk management. And this is especially crucial in the development of unembanked areas, where elements such as a direct view of water, the creation of new water experiences, and the preservation of cultural-historic characteristics are often deemed very important.

This is in line with the general guidance for CBA of Romijn and Renes (2013b) that says to '*consider doing a cost-effectiveness analysis (CEA) if all the measures to be investigated have the same (main) effect'* (e.g., the reduction of flood risk) or *'if the main effects cannot be properly measured or monetised, use the principles of CBA as a conceptual framework. This will help to structure the decision-making, but will not result in a CBA and may not be called a CBA.'* Moreover, as formulated in the general guidance *'a CBA stands or falls on the degree to which the effects of a measure can be determined and valued. The better that can be done, the more useful the CBA will be in supporting the decision-making.*'

In addition to this, MCA is very useful tool for supporting decision-making on local flood risk measures, as it does not quantify effects in monetary terms but assigns a weight to each effect. However, careful attention must be paid to preventing double-counting of effects, and MCA is less objectively than CBA since decision-makers can determine the weights of criteria. Nonetheless, MCA can be combined with CEA and CBA. However, when combining with CBA, it should be clearly phrased what form of CBA is used, e.g., a 'partial' CBA (i.e., a CBA that solely focuses on (one) direct effect(s) that is/are monetizable, for example reduction of flood risk).

SQ2: What decision-making methods have been used in recent projects in unembanked areas, and what can be learned from these practical examples?

For answering the first part of the sub-question, Table 9 provides a summary of the decision-making tools used in the examined cases.

Table 9: Overview results case studies

Case study	Level of flood risk measure(s)	Decision-makings tools and process
Rotterdam, the Netherlands: Issue level policy	Regional	- Different risks assessment methods over time - Current issue level based on form of CBA that addresses the trade-off between site elevation and flood risks
Rotterdam, the Netherlands: Merwe-Vierhaven (M4H)	Area / building	- Mix of quantitative assessment (form of CBA) and qualitative assessment (time/flexibility, feasibility, effectiveness, and spatial identity)
Vlaardingen, the Netherlands	Area	- MCA incl. spatial quality, technical elements, water safety, management and maintenance and costs
Zwolle, the Netherlands	Area / building	- Principles (*uitgangspunten),* would later be used as criteria for MCA
Copenhagen, Denmark	Regional	- CBA for storm surge barriers
Hamburg, Germany	Area / building	- Principles (*uitgangspunten)* and strict regulation

Furthermore, to arrive at realistic and feasible adaptation measures in unembanked areas, it is essential to consider the existing built environment and local characteristics. For example, elevating an entire area to a specific safety level (e.g. issue level) may not always be feasible or desirable due to constraints imposed by assets such as (critical) infrastructure, trees, and cultural heritage, as well as considerations related to the connection with surrounding areas. Moreover, allowing water onto the quays during high tides can be a deliberate choice, provided that properties and public spaces are designed accordingly. This approach fosters a new living environment and contributes to the creation of greater water awareness among users and residents in unembanked areas.

The real-world examples and literature highlight that raising sites/buildings or implementing barriers in public spaces is often the most economically efficient solution from a flood risk perspective. However, for unembanked areas, considerations related to the experience and connection with water, along with the preservation of cultural (historical) landscapes and quality of nature, play a crucial role. Therefore, to develop a tailor-made approach in unembanked area development, these factors must be taken into account. From Table 9, it is evident that MCA, grounded in various principles (*uitgangspunten)* that are translated into criteria such as flood risk reduction, spatial quality, (cost)-effectiveness, and other relevant effects is widely used in unembanked area development to arrive at a set of measures.

SQ3: What are the conditions and needs regarding the decision-making process of local flood risk measures in unembanked areas from the perspective of various stakeholders*?*

Numerous parties are involved in flood risk management and spatial planning, making decision-making for adaptation measures complex. The ongoing developments in climate-adaptive construction and discussions on where and how to build add to the complexity. Stakeholders are currently grappling with how to interpret directives like *'Water en bodem sturend'* or how to use the *'Landelijke maatlat voor groene klimaatadaptieve gebouwde omgeving*'. This leaves them in the early developing phase in their approach to climate-adaptive building.

Stakeholders highlight that, despite existing rules and policies, they struggle with how to manage their responsibilities for unembanked area developments and since there are mutual dependencies, this often leads to each party looking to the other. This challenge extends more broadly to climate-adaptive measures, as parties find it difficult to determine who should be held accountable for taking what actions. Moreover, awareness for unembanked areas remains low, and it became clear that there is still a false, low or non-existing risk perception for floods in the unembanked areas among stakeholders. People should be more aware of unembanked areas and the flood risk involved, so there is a urgent need for better communication.

Moreover, for developing parties and financial institutions, the risk profile of an asset matters more than labels like 'embanked' or 'unembanked'. All stakeholders emphasize the need for clear, legally established definitions, guidelines, and frameworks for climate-adaptive construction. They advocate to make instruments like '*Landelijke maatlat voor groene klimaatadaptieve gebouwde omgeving*' mandatory rather than voluntary.

Clearer guidelines and definitions, obligatory for all, would level the playing field for involved parties. In addition to this, stakeholders call for clarity and uniformity on the use of data, maps and information services in order to determine risks levels consistently. Adding reliable risk labels to assets (similar to the energy labels) is useful for stakeholders, yet this is complex as it requires very accurate up-to-date information on a local level.

Moreover, a collaborative effort involving all evaluated stakeholders, with the government possibly playing a central role, could be advantageous. A prominent role for the (national) government is also envisioned in raising awareness among citizens and businesses about climate risks. Lastly, there is a growing demand for collaboration among diverse parties, both public and private, making it able to share knowledge.

MQ: What evaluation methods are appropriate to use in the decision-making process for local flood risk measures in area development in unembanked areas, and what are the needs of stakeholders regarding the decision-making process?

This research question has been addressed using qualitative research methods. Firstly, a literature review was conducted to explore various evaluation methods employed in flood risk management and how they are utilized in the decision-making process for unembanked area development. Subsequently, case studies were examined, supported by literature and interviews, to understand how decision-making for flood risk measures work in real-world examples and what lessons can be drawn from them. Finally, through literature and interviews, the role and interest of stakeholders towards construction in unembanked areas were investigated, along with their needs regarding the decision-making process.

To support decision-making for local flood risk measures in unembanked area development, various evaluation methods are available. In this study, methods such as cost-benefit analysis (CBA) and its different forms, cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), and impact assessments (IA), commonly used in flood management, have been explored.

Throughout the study, it has become evident that unembanked areas require a tailor-made approach to develop a suitable set of measures. In this context, social values and intangible criteria such as spatial quality, nature, cultural heritage, stress from floods, flexibility, and feasibility are crucial to include for robust decision-making on adaptation measures. Yet, there is a lack in key figures and adequate valuation methods for these social and intangible effects.

For this reason, a MCA is a very appropriate tool to support decision-making on local flood risk measures in unembanked area development, as it is possible to include all relevant effects without having to measure and monetize them. Moreover, MCA can be combined with CEA or a form of CBA to quantify the effects that are measurable and monetizable. However, when combining with CBA, it should be clearly phrased what type of CBA is used, e.g., a ‘partial’ CBA (i.e., a CBA that solely focuses on (one) direct effect(s) that is/are monetizable, for example reduction of flood risk).

Thus, to support decision-making on local flood risk measures in unembanked area development, the combination of MCA with CEA or a form of CBA is well suited. This is confirmed by literature and from real-world examples. This approach enables the balanced consideration of both essential quantitative and qualitative criteria. Moreover, using MCA facilitates the integration of diverse stakeholder perspectives, promoting a more inclusive decision-making process, which ultimately ensures broad consensus on the decisions made.

As for the keys needs and conditions for stakeholders, there is a demand for more legal assurance for climate-adaptive construction and strict rules to comply with when building in unembanked areas. Stakeholders highlight this as the biggest sticking point at the moment. For unembanked areas, there is a lack of national safety standards and uncertainties about e.g. what are to be considered vital and vulnerable infrastructure. Financial institutions and developers indicate that they would benefit if the requirements for climate-adaptive construction in unembanked areas were established in legislation and regulations. This is something that should be done at the national level, such as legally defining requirements for climate-adaptive construction, or at the local level, as demonstrated by the city of Rotterdam's adoption of the issue level policy. Furthermore, there is a strong need for a uniform determination of flood risks so that each asset receives the same reliable risk label. There is a growing demand for collaborations between private and public parties, both among themselves and collectively. And finally, there is a central role for the government in improving flood risks awareness and communication.

7

DISCUSSION & RECOMMENDATIONS

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In this chapter, a critical review of the conducted research will take place. It involves reflecting on the research and delving into its limitations. Finally, recommendations for further research will be offered, along with advice on how the municipality of Rotterdam can utilize these results.

Discussion

First and foremost, from the start of this research, there was a significant focus on cost-benefit analysis. This emphasis was rooted in the fact that Rotterdam's adaptation strategies and examples from other graduates heavily relied on CBA. Initially, attempts were made to enhance the previous research with social values and distribution effects since the literature emphasized the importance of incorporating social effects, which had been scarcely addressed in existing CBAs. Additionally, adding distribution effects was considered to offer a better insight into the cost and benefit distribution, which was a commonly expressed need among various stakeholders in exploratory interviews. Therefore, a significant amount of time has been dedicated to searching relevant data and key figures (this was part of the reason why the case studies have been done), especially concerning spatial quality and the preservation of cultural heritage. Finding useful information was proven to be challenging, and throughout the research, it became evident that quantifying social costs and benefits is extremely challenging due to the lack of adequate valuation methods.

Despite the limitations of CBA that became apparent during the study, there has been a prolonged insistence on searching for suitable data and information. There has been a strong adherence to CBA as the sole useful instrument to support decision-making for adaptation measures in unembanked area development. However, other techniques and methods that could have been compared were overlooked in the beginning. For example, the multi-criteria analysis, as revealed by the Vlaardingen case study, is also a commonly used tool in flood risk management. Reflecting on this research, it would have been wiser to first look at the usefulness of certain evaluation methods, so that eventually this research could also have contributed to improving a framework to support decision-making in unembanked area development.

This aligns directly with one of the limitations of this study, as it has only focused on a few evaluation methods, while there are, of course, more variants and methods available. There are also other economic decision support tools used in adaptation assessment that are not considered in this research at this moment, such an uncertainty framework (iterative risk management), and alternative tools that more fully account for uncertainty (real option analysis, robust decision-making, and portfolio analysis). It is crucial to note that these tools still focus on economic decision-making, while in the context of area development in unembanked areas, other social aspects and criteria like flexibility are equally important.

Moreover, conducting multiple case studies could have been more beneficial. Apart from Rotterdam, Dordrecht is one of the largest municipalities with significant urban unembanked areas. Although there was ongoing contact with employees from the municipality of Dordrecht throughout the research, it was impossible to conduct additional case studies due to time constraints. While it is debated whether this would have provided different insights, it is important to acknowledge that this is a limitation of the research.

A similar limitation applies to the number of interviews conducted. It was not possible to conduct more interviews with stakeholders. For instance, only one conversation took place with a developer. This developer had prior experience with unembanked projects, which might shape their perspective differently from a developer who has never engaged in such projects. A more comprehensive understanding of risk governance might have been achieved through more extensive discussions. The number of interviews and the time available for the research did not allow for further validation of these results, but they contributed to presenting a general overview.

On a related note, certain stakeholder groups were excluded from this research, with one of the most significant being the perspective of the residents themselves. How do they view living in unembanked areas, and are they willing to take on these risks? What trade-offs would they make between safety and the experience of water? How can awareness among residents regarding living in unembanked areas be raised? In future research, it is important to include this stakeholder group, even though it can be challenging because one resident might not represent the entire group.

Additionally, the complexity of the problem is worth discussing. Climate-adaptive building is relatively new, and many parties involved have only recently started grappling with it. This research further complicates matters by delving into climate-adaptive measures in unembanked areas, which function under different legislation than areas within dikes.

Furthermore, the research solely focuses on flooding, whereas urban areas also face other challenges such as drought and heat concerning climate adaptation. This research did not examine the potential synergies with other projects. However, it is conceivable that a decision-making framework for unembanked areas could also consider opportunities for synergies with other transitions and challenges within the city.

Although this research has its limitations, the findings align well with previous studies on flood risk measures. Nilessen (2019) asserts that the effects on spatial quality are not easily quantifiable and that despite national and regional strategies, uncertainties remains on taking suitable measures at a local level. Consequently, there is a clear need for a qualitative analysis of the effects on nature and spatial quality, emphasizing the necessity for a methodology to analyse spatial effects at a local level. Moreover, De Moel et al. (2014) also indicate that considerations beyond (cost-)effectiveness play a role in decision-making for flood measures in unembanked areas. To incorporate additional values such as preserving a direct view of the river or maintaining the identity of an area, they suggest that '*this should ideally be based on a thorough analysis of various measures from all layers* (i.e. layers of MLS-concept) *and their pros and cons using a common framework.'*

While this research does not explicitly focus on the development of such a framework, results of this research build upon these insights, demonstrating that by combining MCA with CEA or a form of CBA, it is possible to incorporate both quantitative and qualitative information. Moreover, this aligns with the research of van Veelen (2016) on adaptation pathways in unembanked areas, who argues that adaptation measures should be evaluated based on performance criteria such as spatial quality, flood reduction, cost-effectiveness, and other relevant effects. The later-formed adaptation pathways are evaluated using an MCA that weighs factors like flexibility, (cost-)effectiveness, and spatial considerations. Thus, the conclusion to combine MCA and CEA or a form of CBA as a useful evaluation method is in line with this.

Finally, and the most important discussion point for this research is the role of evaluation methods in decision-making process. CBA, MCA, CEA or IA are all used to support decision-making in flood risk management, however, the final decision is always up to the decision-maker. This was also addressed by de Moel et al. (2014) as they conclude that '*in the end, it is up to decision makers to make a final choice between measures from the different layers.´*

This is evident in a real-life case of unembanked construction in Kraanbolwerk, Zwolle, where the set safety level was lowered during construction phase, ultimately reflected in the structure of the apartment. In Figure 35, a difference in height is noticeable between the two balconies on the left side compared to the other balconies on the ground floor, as indicated by the blue arrows.

Figure 35: Construction in Kraanbolwerk, Zwolle (Photo by author)

Recommendations

In general

The main recommendation would be to create a guideline for area development in unembanked areas in which the different evaluation methods can be used during several phases of the decision-making process. First, a form of CBA on a regional level could be used to establish safety standards like the issue level. Once this is done, that safety level should be legally safeguarded by the municipality in zoning plans as the applicable safety standard for that area. If, during the development of unembanked areas, it proves unfeasible or undesirable to raise the area and/or buildings to the established safety level due to the constraints in the existing built environment or other motivation, then a determination should be made regarding the best alternative solution. This can involve measures such as dry-proof or wet-proof building, or interventions in public spaces. This determination should be made through a MCA combined with criteria such as flood risk reduction, (cost-)effectiveness, flexibility and other social values. Follow-up research should focus on creating a guideline or map for area development in unembanked areas, advising what steps municipalities, developers and housing corporations should take in order to guarantee successful designed unembanked areas.

Moreover, in general, there is a growing need for clear definitions, guidelines, and frameworks for unembanked building and climate-adaptive construction. Several stakeholders address that it crucial that these guidelines and frameworks are legally enforced. This can be done both on a national level, e.g., by making *'Landelijke maatlat groene klimaatadaptieve gebouwde omgeving'* mandatory, and at municipal level, e.g. issue level in zoning plans. Future research can explore what these definitions and guidelines should entail and how they can be incorporated into legislation.

Communication regarding unembanked areas and the associated risks remains vital for creating awareness. It is evident that unembanked areas are not universally well-known. Therefore, further research should focus on how awareness of flood risks in unembanked areas can be raised, with a strong emphasis on effective information dissemination to prevent misconceptions.

Future research can also focus on validating this study. While this research was primarily concerned with understanding the decision-making process for flood risk measures in unembanked areas, subsequent research should confirm the accuracy of the findings. This also hold for the stakeholders interviews. By conducting more interviews, it can be validated how stakeholders perceive this issue and confirm their specific needs for decision-making process.

Additionally, future research should involve closer collaboration with urban designers, landscape architects, and spatial planners to establish a framework outlining the criteria by which measures should be evaluated.

Furthermore, subsequent research could explore the possibility of defining a standard safety level for unembanked areas, similar to what exists for areas protected by dikes. Currently, each municipality makes its own decisions in this regard, but having a consistent safety level for unembanked areas across the Netherlands could be beneficial. This would also make it clear which areas can meet these safety standards and which cannot. Floodplains (*NL: uiterwaarden)* for example, will fail to meet the required safety levels due to their susceptibility to flooding.

Municipality of Rotterdam

For the municipality of Rotterdam, it is crucial to legally secure minimum requirements for unembanked construction. This means legally codifying non-negotiables, such as setting the minimum safety level as the base construction level. The issue level could be used for this. Stakeholders have expressed a strong need for this, and for the municipality of Rotterdam, it is important that these standards are formalized and be taking into account, for example in zoning plans.

Increasing awareness of unembanked areas among the public is also essential. This goes beyond simply publishing information on websites; it involves making it visibly clear within the areas themselves. For example, consider the dike wall in Afrikaanderbuurt, which serves as an excellent example of how to differentiate between what is inside the dike and what is outside. Additionally, emulating approaches used in places like Dragør, such as installing markers indicating potential water levels, can significantly contribute to raising awareness about flood risks in unembanked areas.

Engage relevant stakeholders, such as residents, developers, and interest groups, more actively in the decision-making process for flood risk measures. Gather their perspectives on risks and potential actions. While this is already happening to some extent, there is room for increased citizen participation in decision-making. It would be wise to consider the needs of private entities like developers and housing corporations in the policy framework. Although platforms like the Covenant Climate-Adaptive Construction exist, they are not fully utilized for knowledge sharing. Rotterdam could set an example for smaller municipalities, leveraging its extensive in-house expertise in coastal area development. The municipality can take a more proactive role.

Addressing challenging topics, like defining vital and vulnerable infrastructure, is currently avoided due to its complexity. However, there is a strong demand from various parties for clear definitions and guidelines, making it beneficial to eventually make decisions on these matters.

Lastly, the municipality of Rotterdam is developing a societal values model for asset management, inspired by the 6-capitals model (natural, financial, material, human, intellectual, social). Integrating this with future adaptation strategies could be valuable. It may not serve as a calculation model (as they are also trying to monetise all these values), but could be utilized as KPI’s to analyse effects on assets in unembanked areas.

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Appendix A – Overview expert interactions

In this Appendix an overview of relevant interactions with stakeholders and experts is given in Table 10. Next to these interactions, repetitive meetings were also attended on several occasions. These include weekly meetings within the municipality of Rotterdam of *Team Hoogwater* and *Werkgroep Herijking Uitgiftepeilenbeleid*. The table shows the date, type of interaction, organisation(s) present and topic. In case of bilateral meetings, the name has been omitted for privacy reasons, but the function of the person concerned is mentioned. To keep the table clear, in the case of interactions where several people were present, the participating organisations are mentioned, but the functions are excluded.

Table 10: Overview interactions with experts during research

No	Date	What?	Organisation(s)	Function	Topic
1	20-03-23	Workshop 'Weer Verandert Alles'	Municipality of Rotterdam		Workshop with urban planners
2	27-03-23	Meeting	Deloitte & Rotterdams WeerWoord		Role financial sector building climate adaptive
3	27-03-23	Bilateral meeting	Municipality of Rotterdam	Advisor water strategy and development	Water safety in Rotterdam
4	28-03-23	Semi-annual gathering	Partners of *Bouwconvenant Zuid-Holland*		*'Sprint Bouw Adaptief'* : ongoing developments in building climate adaptive
5	28-03-23	Bilateral meeting	Municipality of Rotterdam	Spatial planner	Water safety in Rotterdam
6	28-03-23	Workshop 'Weer Verandert Alles'	Municipality of Rotterdam		Workshop with department of *Stedelijk Stadsbeheer*
7	30-03-23	Annual Congress	Stitching Kennis Gebiedsontwikkeling (SKG)		Ongoing developments in area development and climate change
8	31-03-23	Meeting	Water boards, Rijkswaterstaat, Province of South Holland, Deltares		Transition pathways in the Esch, Rotterdam
9	03-04-23	Bilateral meeting	Municipality of Rotterdam	Policy advisor building physics, circularity and integral sustainability	Sustainable and circular urban development
10	05-04-23	Bilateral meeting	Municipality of Rotterdam	Urban planner	Sustainability and placemaking in Rotterdam

11	11-04-23	Bilateral meeting	Municipality of Rotterdam	Advisor urban water, subsurface and water safety	Water safety in Rotterdam
12	12-04-23	Bilateral meeting	Municipality of Rotterdam	Advisor on sustainable area development	Developments on sustainable in urban areas of Rotterdam
13	12-05-23	Meeting	Red & Blue and Deloitte		Climate adaptation & financial sector
14	17-05-23	Field visit	Municipality of Zwolle		Knowledge exchange on strategies for unembanked areas
15	23-05-23	Bilateral meeting	Municipality of Rotterdam	Project manager area development	Area development in M4H
16	24-05-23	Bilateral meeting	TU Delft	Assistant Professor management in the Built Environment	Urban climate finance
17	25-05-23	Meeting	Municipality of Rotterdam, Municipality of Dordrecht, ING, ABN AMRO, Achmea		Technical and financial feasibility of foundation challenge in housing construction
18	26-05-23	Bilateral meeting	TU Delft	Associate professor	Social cost-benefit analysis
19	5-06-23	Conference	Multiple public, private and semi-public parties		Deltaprogramma Rijnmond Drechtsteden
20	23-06-23	Bilateral meeting	TU Delft	PhD candidate urban development management	Climate adaptation urban areas Rotterdam
21	23-06-23	Bilateral meeting	TU Delft	PhD candidate climate adaptation engineering	Climate adaptation and unembanked areas
22	30-06-23	Bilateral meeting	Royal HaskoningDHV	Hydraulic engineer and water safety consultant	CBA and adaptation strategies Rotterdam
23	24-08-23	Meeting	Municipality of Rotterdam and		Knowledge exchange building

			municipality of Dodrecht		in unembanked areas
24	07-09-23	Quarterly meeting	Municipality of Rotterdam, Dordrecht Hoekse Waard, Voorne aan Zee, Den Haag, Rijkswaterstaat, HH Delftland, HHSK, WSHD, VRR, Province of South Holland, Ministery of I&W, Port of Rotterdam		DPRD Platform Buitendijks
25	08-09-23	Annual Symposium Red&Blue	Multiple parties of the consortium and other external invitees		Creating actionable climate science
26	26-09-23	Bilateral meeting	Rijkswaterstaat	Software coordinator flood risk management	Researches on unembanked areas